DIGEST OF INDUSTRIAL AND TECHNICAL DEVELOPMENTS

Nuclear Power at Imperial College

AN academic appointment of more than ordinary interest follows the creation of a chair of nuclear power at the Imperial College of Science and Technology. The first holder of this chair will be Dr. J. M. Kay, who is 35, a graduate of Cambridge and an ex-demonstrator in the chemical engineering department of that university. In 1952 he became chief technical engineer of the Industrial Group of the atomic energy organisation at Risley. He has since 1955 been acting as a consultant in the field of nuclear power and in related industries.

American Nuclear Developments

THE U.S. Atomic Energy Commission's current budget is being augmented by a special additional appropriation of $112.5 million—about £40 million. The original estimates for operating expenses and construction work were respectively $1672 and 144.2 million. The extra money is called for by the acceleration of the development and production of atomic power stations and nuclear weapons. The U.S. Services are also spending large sums on nuclear developments. The Navy has virtually finished with conventional submarines, and aims to go over to nuclear power completely inside twenty years. The second atomic submarine, *Sea Wolf*, is completed and over a dozen similar vessels are under construction or authorised. A nuclear-powered missile cruiser of 11,000 tons is being designed, and also a power unit for an aircraft carrier. There is at least one project for an atomic aircraft engine.

Chemical Engineering in the Coal Industry

THE recent conference at Stoke Orchard, which was organised by the National Coal Board, discussed some of the chemical engineering techniques which have been applied to problems such as the shortage of good quality coking coal and the production of smokeless fuels from low-grade coals. Britain, like many other European countries, is faced with the need to maintain and improve the quality of coke used for blast furnaces at a time when the source of this material is steadily shrinking. At the same time another problem will arise in Britain from the impending legislation on air pollution, which may be expected to result in the restricted use of smoke-producing fuels. This means that a considerable quantity of smokeless fuel suitable for burning in domestic fireplaces and boilers will have to be manufactured. These two problems apply to all the European countries to varying degrees.

The papers presented by members of the N.C.B. team at Stoke Orchard were concerned mainly with the production of smokeless fuel and with the by-product possibilities. Processes were described for the making of smokeless briquettes from different varieties of coal, such as caking steam coals on the one hand and low-rank coals on the other. The former are unsuitable for manufacture of carbonised briquettes because of their excessive agglutinating and swelling characteristics. One paper described a plant in which such fuels are given a mild fluidised oxidation treatment, which is successful in controlling and reducing these properties to useful proportions. These treated fuels are successfully made into briquettes by means of a small proportion of binder, normally pitch.

In the case of coals of low rank, de-volatilisation is necessary, and here again the fluidised technique has been employed. However, the coal thus treated is deprived of its property of 'stickiness.' This is overcome by adding coal and pitch together to the pre-carbonised coal, which is then briquetted quite readily at a temperature of 350-450°C and at a pressure of 2 tons per square inch at the press. The influence of a number of variables upon the mechanical strength of briquettes was also outlined.

Carbonising with Hot Sand

THE final carbonising of briquettes had been successfully accomplished on the small scale by means of heat supplied from hot sand. The pilot-plant process operates continuously and has the advantage of greatly increased heat transfer rates compared with carbonising carried out by means of hot gases. The process of de-volatilisation received attention in a French paper, which described an elegant pilot plant for coal treatment by a fluidised process. The aim of this work was the replacement of coke dust normally used in the manufacture of blast-furnace coke prepared from Lorraine coals. In the normal way, good quality blast-furnace coke is made from this coal by mixing coke dust in with the charge fed to the coke ovens. With coke dust now in short supply in France, a substitute is needed, and the semi-coke produced by the fluidising process has been found to be satisfactory. The product from this plant is also suitable for use in iron oxide sinter plants.

The visitors to the conference had the chance of inspecting a number of pilot plants, including the continuous briquetting unit using hot sand. We noticed that one unit (for the fluid-bed de-volatilisation of coal powder) was linked up with an analogue computer, which had been installed to analyse the heat flow through the fluidised bed.

£16 Million Extensions at Wilton

I.C.I. have just announced their decision to erect a third oil-cracking plant at Wilton. Their first oil cracker came into operation in 1951, and the second will come on stream towards the end of this year. The new plant will be even larger, and it is scheduled to be ready early in 1959. Its main product will be ethylene required for polythene synthesis. Additional plant will be erected to raise the company's capacity for "Alkathene" in Britain to over 90,000 tons a year. These extensions, together with ancillary services, will cost over £16 million.

Chemical Engineering in Edinburgh and Glasgow

EDINBURGH'S new department of Chemical Technology, under Prof. Kenneth Denbigh, is a joint one linking the university with the Heriot-Watt College. The members of the staff rank as full members of the staff of both institutions, and their salaries are on the university scale. We wish every success to this interesting new experiment in collaboration between a university and a technical institution. A chair at Edinburgh in this subject was established in 1855, and was the first of its kind in Britain. It lapsed, however, with the death of its first occupant, Prof. George Wilson. Two streams of students will enter the new department; the first will take the degree of Bachelor of Technological Science of the university (honours and ordinary degrees will be awarded) and the second will take the Associateship of Heriot-Watt College in Chemical Engineering. The courses, including the one for the ordinary degree, extend over a period of four years. When the new premises are completed, it will be possible to accept about 25 students a year, of whom about 15 will be degree students and the rest associateship students. The two streams enter the department at the end of the second year, and the chemical engineering teaching will be given mainly in the third and fourth years. Two Institution of Chemical Engineers assessors, Prof. J. M. Coulson and Dr. J. F. C. Gartshore, reported on Edinburgh's former Technical Chemistry course, and several of their recommendations have been embodied in the new curriculum.

A chair of chemical engineering has just been created at the Royal Technical College, Glasgow, within the Department of Mechanical, Civil and Chemical Engineering. The professor of chemical engineering will be Dr. A. W. Scott.

How Many Engineers are Needed?

THE recent de Witt report ("Soviet Professional Manpower"), which gave details of the rate at which Russia is expanding its output of technologists, produced near-panic in both the U.S.A. and Britain in top political circles remote from the world of science and technology. Technologists in both countries are now beginning to express doubts about the politicians' attitude, which could seriously upset the well-laid plans that exist for developing technological education on both sides of the Atlantic. The comment of Caltech's president, Lee A. DuBridge, supplies wise counsel on this matter and is well worth the attention of British technologists and education experts. He says: "It is true that in Russia more men and women received degrees in science and engineering than in the U.S. So what? Maybe that is because in the past 100 years they have so neglected their technical strength that they must now exert strenuous efforts to build it up. If this is true, then our rate of production should not be determined by their weaknesses—only by our own. Let us ask how many engineers we need to do our job, and not take over their figures or the numbers they require to do their job." Politicians are notorious amateurs in most matters affecting education, and this problem of technological training is far too serious to be left to amateurs.

The Dynamic Behaviour of Chemical Plant

THE dynamic characteristics of plants and processes formed the subject of a recent conference organised by the Society of Instrument Technology in Cambridge. A full day was devoted to the dynamic behaviour of specific items of chemical plant. Mr. A. H. Horton of I.C.I. described the frequency response of a jacketed pan to variations in the flow of heating steam. A set of differential equations for the system were found to predict the behaviour once the heat-transfer coefficients had been determined experimentally from the steady state behaviour. This same pattern, of experimental determination of static behaviour followed by theoretical prediction of dynamic response, emerged in other papers, and it was evident that a completely theoretical treatment of problems involving boundary layer properties is not yet possible. Mr. R. L. Day gave his results for a similar study made on a distillation column re-boiler, and papers describing experimental and theoretical work on laboratory distillation columns were presented by Mr. W. L. Wilkinson and Dr. W. D. Armstrong (Cambridge University) and Dr. H. Voetter (Royal Dutch/Shell Laboratory). Next day an important paper on the application of an electronic analogue computer to the study of a level control system for a refinery distillation column was presented by D. S. Townend (B.P. Ltd.), N. Ream and R. H. Tizard (N.P.L.). Another joint paper dealt with the techniques used in the Royal Dutch/Shell Laboratory for measuring the dynamic response of plant units. All the papers delivered at this conference are due for early publication by Butterworths Scientific Publications.

Chemicals on Humber Bank

THE titanium pigment factories of North Lincolnshire which are on the Humber Bank—British Titan Products, Ltd., at Pyewipe, near Grimsby, and Laporte Titanium, Ltd., at Stallingborough, near Immingham—are still expanding and increasing their plant capacity. This is bringing North Lincolnshire into the front rank of sulphuric acid making and using areas. The first production of British Titan at Pyewipe was started in 1949, when a 100 ton per day contact plant, using sulphur, was coupled to the ilmenite reactor system. In May, 1952, British Titan brought into commission the first flash roaster in the country. In 1955 a further flash roaster was commissioned, and this brought the capacity of the factory up to 300 tons per day of sulphuric acid.

Early in 1956 British Titan commissioned the first turbulent layer roaster in the country, and thereby brought up their capacity by at least another 100 tons per day at a cost of approximately £500,000. By this time the total capital investment in all their process plant and installation had reached some £8,000,000. The full effect of the recent changes is expected to be obtained by early 1957, by which time employment at the factory will have reached about 1200. The acid manufactured on site by British Titan will be sufficient to process some 120 to 150 tons per day of ilmenite.

The other major producer, Laporte Titanium, started production in 1953 with an installed sulphuric acid capacity, based on a flash roaster plant, of about 75 tons per day. But further supplies of acid were made available from the Laporte acid factory at Castleford, some being brought by road, and some being shipped by barge. By the end of 1955 the titanium pigment output at Laporte's had been doubled, and this month it has been announced that new extensions will be commenced that will double the present production. The present plant employs some 600 workers.

Sulphuric Acid at Immingham

THE near future will therefore see these two plants using the best part of 1000 tons of sulphuric acid per day

between them. This diminishes the relative magnitude of the other two principal acid producers—Fisons, Ltd., of Immingham, and Nitrogen Fertilisers, Ltd., of Flixborough, near Scunthorpe. Fisons started production of sulphuric acid at Immingham in 1949 in what was then one of the largest units in Europe, making some 250 tons per day for use in their superphosphate and phosphoric acid plant.

Nitrogen Fertilisers, Ltd., which is a joint venture of Fisons and the West Norfolk Farmers' Co-operative Chemical and Manure Co., was started in 1939 with an acid capacity of 100 to 110 tons per day, the acid being used to absorb site-made synthetic ammonia. At present their plant is being reconstructed to a capacity of some 150 tons per day of acid. Of considerable interest is the fact that they will employ a new burner of their own design, some 15 feet in diameter, which will use sulphur filter cake as raw material.

Another sulphuric acid producer in the locality is the Farmers Company, Ltd., at Barton-on-Humber. In the last eighteen months this firm has brought a phosphoric acid plant into production.

From references in the local press it would appear that at least one of the steel producers in the Scunthorpe area is giving thought to the recovery of sulphur from coke oven gas. This may lead to further capacity for sulphuric acid production. Perhaps more certain is the prospect that when Courtaulds, Ltd., get their new viscose plant going at Grimsby there will be constructed new acid capacity to the tune of 100 tons per day.

The Duke's Conference

THE Duke of Edinburgh's industrial study conference in Oxford was a most unorthodox affair, but eminently successful. The conference organisers had aimed to assemble a carefully selected cross-section of Empire citizens, and that intention was abundantly fulfilled. It was a conference of young men picked as individuals with the capacity of reaching responsible positions in industry within the next twenty years. The Duke's opening address was a notable *tour de force*, on a par to his now famous presidential address to the British Association meeting at Edinburgh. The four basic ideas behind the conference were these, and here we quote the Duke's own words.

First, they had to decide whether there were any past lessons which could help overcome the problems of present industrialisation: could the experience of the industrial north help Africa, for example? The second question was whether the new industries of the Commonwealth could help each other. The Commonwealth countries were a long way apart; some might be more successful than others, or have interesting ideas which had been tried and found unsuccessful elsewhere. Thirdly, he hoped the conference would form some conclusions about what things made for a good works, a happy community and a satisfied individual. The fourth point was made when he referred to the "bewildering variety of shapes" assumed by the simplest industrial problem when it was viewed from different standpoints of the board room, shop floor, research, production and personnel departments, or the trade union. Members and speakers at the conference were chosen in such a way that all these points of view would be put forward. "I doubt if there has ever been such an opportunity for these questions to be thrashed out with such a widespread wealth of experience," said the Duke. Without a doubt, the conference fully exploited this unique opportunity.

The I.C.I. Contingent

THE chemical industry was well represented at Oxford, and among those who attended the opening ceremony in the Sheldonian Theatre was Sir Alexander Fleck. Along with fitters and process hands from I.C.I. Metals Division, Ardeer and Billingham, there were men from I.C.I.'s overseas companies. From Modderfontein came S. A. G. Anderson and J. P. Wapenaar, and I.C.I. A.N.Z. was represented by S. J. Gilbert and R. F. Maddison. Also present were L. Hemsworth, of Canadian Industries, and Y. Khan, of I.C.I., Pakistan. One of the joint managing directors of Metals Division, Mr. Michael Clapham, took part in the activities of one study group.

Cockcroft on Incompatibility Problems

SIR JOHN COCKCROFT, in his opening speech to the Institute of Physics reactor conference, touched on some of the chemical engineering problems involved in the development of power reactors. He said that the principal compatibility problem arising in gas-cooled graphite-moderated piles is due to the reaction between the carbon dioxide coolant and the graphite. This might lead to some mass transfer of carbon from one part of the reactor and its cooling circuit to another. The reaction rate increases with radiation, and the magnitude of this effect is being studied at Harwell. At the temperatures expected in the Calder Hall reactor and in future C.E.A. reactors the effects are likely to be insignificant, but they might be a limiting factor in raising the temperature of the reactor core well beyond 400°C. At higher temperatures it would probably be necessary to find some means of sealing the pores of the graphite.

In water-moderated reactors the principal problem is the compatibility of the hot water with the uranium fuel. Unalloyed uranium is attacked far too rapidly, and if metal fuel elements are used it is necessary to resort to alloying to reduce the corrosion rate. This increases neutron absorption, and it would be better to use sintered uranium oxide fuel elements, which are very resistant to attack by hot water.

Zirconium's Drawbacks

THE hot water has to be compatible with the sheath of the fuel elements, and for this purpose the U.S.A. has developed Zircalloy, a zirconium alloy. Cheaper aluminium alloys are being investigated at Harwell. Compatibility is a necessary condition for the pressure vessel and external circuit material. An obvious but expensive solution is to use stainless steel throughout, or at least stainless steel linings, but stainless steel is hard to decontaminate from fission products, and it is hoped that loop tests now proceeding will show that mild steel can be used if there is adequate control of water conditions.

In sodium graphite reactors the hot sodium is compatible with uranium metal fuel. On the other hand, the sodium must not penetrate the pores of the graphite. The sodium must be kept away from it, and one feasible solution is to can the graphite in hafnium-free zirconium sheet. Unfortunately, zirconium will take up any oxygen leaking into the system. Formation of the oxide leads to embrittlement, and so the onus is thrown back on the designer to devise methods of keeping the oxygen content of the sodium below 10 parts per million. This difficulty may well force the designer to use a calandria design.

Compatibility problems are still more acute in the aqueous homogeneous reactor, for it has been found that the corrosion rate of the zirconium vessel holding the core

fluid (uranyl sulphate) increases strongly with radiation intensity. So a search has to be made for corrosion inhibitors, or other materials have to be found which are more corrosion-resistant. Speaking of the need to recycle the fuel of large reactors, he said that the aqueous solvent extraction processes (described by G. R. Howells in our May, 1956, issue, pp. 8-11) would achieve low separation costs of the order of £1000 per ton of uranium metal processed. (The initial fuel element cost is £15-20,000 per ton.) Fabrication of the separated plutonium will need to be done in closed boxes because of its toxicity, and here is a good opening for automatic remote control. Development work now in progress will shed light on the costs of fabrication under such conditions.

Chemical Engineering on the Farm

AT the present time chemical engineers are interested in two kinds of plant protection problems. First, there is the manufacturing side of the various insecticides, fungicides and herbicides that farmers need. Secondly, there is the question of how best to apply the chemicals to achieve the maximum protective effect. At the recent international conference which Plant Protection organised at Fernhurst, one paper dealt with the mechanics of producing sprays of different characteristics, and this was delivered by Mr. R. P. Fraser, of the Chemical Engineering Department of Imperial College. New requirements have arisen because of the trend towards low-volume spraying, which minimises water transport, especially in arid areas. With some modern crop protection chemicals, for example selective herbicides, only a few drops per leaf or per plant are required to do the trick. The size of drop required may be as low as 10-30 μ and as high as 300 μ. Mr. Fraser has of course done a great deal of very valuable work on the atomisation of fuels, and recently he has been using the same research techniques for the investigation of the atomisation of agricultural sprays. At Fernhurst he showed some remarkable high-speed photographs which revealed the way in which the design of atomisers affects such properties as drop size in a spray. He discussed the relationship between drop size and adequate toxicity in liquid insecticides. We gained the impression that manufacturers of spraying equipment would find it to their advantage if they sought out Mr. Fraser and had a chat about ways and means of applying his discoveries in practice.

Reinforced Plastics

IN our May Digest (p. 2) there was a note referring to an S.C.I. Chemical Engineering Group meeting at which Mr. A. de Dani, of Fibreglass, Ltd., talked about the use of reinforced plastics in the chemical industry. Our note mentioned the contribution which Mr. L. H. Vaughan, of the Research and Development Department of Bakelite, Ltd., made to the discussion after the lecture. Mr. Vaughan has written to us to stress that the main point which emerged from the discussion was that phenolic-resin-bonded glass laminates have better heat resistance than laminates bonded with polyester resins, and therefore they should prove of interest to chemical engineers as well as to the aircraft industry. He adds that the cost of a phenolic resin for low-pressure laminating would be of the order of 2s. 6d. to 3s. 6d. per lb depending on the scale of production. The main theme of the lecture itself was concerned with glass fibre bonded with polyester and epoxide resins. The reference in the discussion concerning the phenolic-resin-bonded laminates followed a question put to the lecturer about heat resistance which he passed over to Mr. Vaughan.

Crown Use of Unpatented Inventions

THE Crown should have permanent powers to authorise the use of unpatented inventions and unregistered designs in connection with defence and civil defence contracts. This recommendation has been made by a small committee comprising Sir Harold Howitt, Sir Robert Barlow and Mr. John Megaw, Q.C. The committee's report (Cmd. 9788, H.M.S.O., one shilling) details the kind of safeguards which are required to protect the industrial interests involved. The Government have accepted the committee's main recommendations with one significant modification. The committee considered that the taking of certain decisions on these matters should be confined to the appropriate Minister or the permanent head of his department. The Government, however, prefers to guarantee that administrative steps will be taken to ensure that these decisions are taken only by Ministers or senior officials. The President of the Board of Trade will be discussing the subject with industrial organisations before introducing the necessary legislation, which will enable the emergency powers under which Government departments have been acting to be revoked.

Airborne Effluents

MUCH stricter legislation designed to minimise the tremendous amount of damage that is done by airborne effluents is on the way, and the British public will be wholeheartedly behind the "Clean Air" Act which will soon be on the statute books. Industrialists will now have to give attention to the importance of ensuring that effluents from chimney stacks are discharged at the best possible height to achieve maximum dilution and dispersal. There was a time when there was little basic information to guide those who had to decide on the height of a new stack, but in recent years the fundamental problems involved in the dispersal of airborne effluents have been studied by a number of people. Outstanding names in this connection are Sir Graham Sutton (who contributes an article on the subject to this issue of *British Chemical Engineering*) and C. H. Bosanquet, of I.C.I., Billingham. The latter, we understand, has just written an important paper on the rise of a hot smoke plume from a chimney, which we hope to see in print soon. Curiously enough, the best book dealing with the fundamental aspects of this subject is "Meteorology and Atomic Energy," recently published by the U.S. Government Printing Office (price 1 dollar). This most valuable document contains much to interest all technical men who have to cope with problems of smoke and other airborne effluents, and it provides a set of nomograms that are useful for atmospheric diffusion calculations, including those based on Sutton's maximum concentration equation—Equation 2—given on p. 203 of this issue.

Acknowledgment

THE nomogram (No. 2) for determining pipe size in the region of viscous flow published on p. 162 of the July issue of *British Chemical Engineering* was based by permission on a nomogram originally prepared by General Engineering Co. (Radcliffe), Ltd., of Radcliffe, Lancs.

BCE 227 for further information

Victoria Instruments

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SPECIFICATION:

The instrument consists essentially of a high quality Pyrex glass detector element bearing 2 Pt/Pt 13% Rh thermocouples in the hemispherical surface, and mounted on a probe 1 inch in diameter and 6 ft. long. Cooling air and compensating leads from the other end of the probe connect to a box (24 in. x 10 in. x 6 in.) of good quality hardwood fitted with Rototherm, double range voltmeter and millivoltmeter and a 5 range microammeter. All these instruments are first grade accuracy (B.S.S. 89) having spring mounted movements and are built into a single unit which is internally earthed.

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Box	...	30 lb. (14 Kg.)

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The probe is inserted into the gases under test and the detector element temperature is controlled by the admission of cooling air from some suitable source (e.g. a small compressor) to its underside. The two thermocouples measure this temperature. When the surface is cooled below the dewpoint of gases they also become the electrodes of a "cell", the conductivity of which is recorded on the microammeter.

The detector element is constructed in such a way that its temperature can be controlled at fixed temperatures below the dewpoint for long periods, and comparative measures of the amounts of sulphuric acid condensed out at any selected temperature can be made.

The instrument is of particular value in determining the temperature range over which corrosion by sulphuric acid may be expected.

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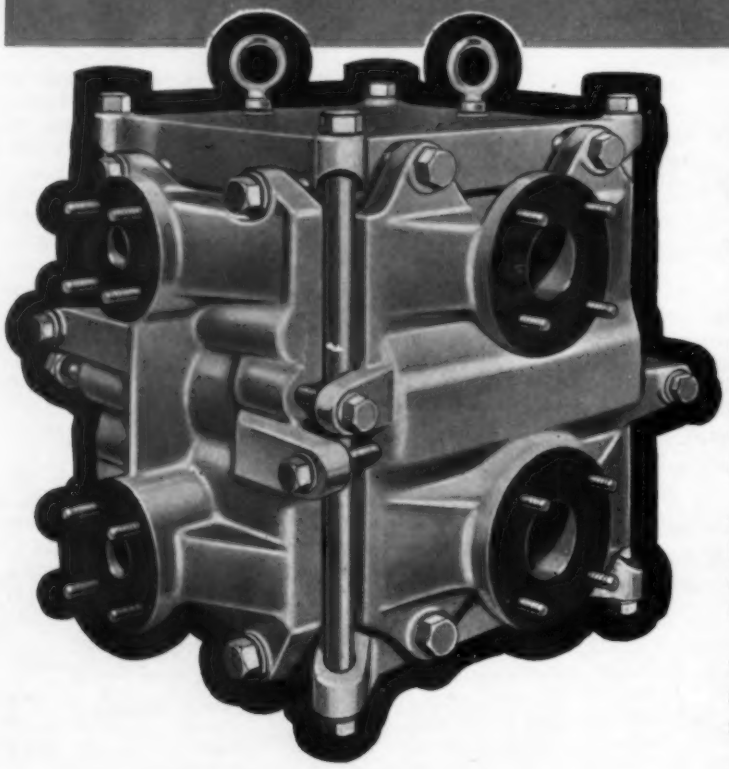
Heat exchanger standardisation



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BRITISH CHEMICAL ENGINEERING
A HEYWOOD TECHNICAL PUBLICATION

Raising a Revolutionary Army

A SECOND Industrial Revolution is now in progress which demands revolutionary changes in the educational system of this country. Our Government has accepted this fact and has produced elaborate paper plans for increasing the output of technologists and technicians to meet the country's industrial needs. All round the proposals made in the recent White Paper on Technical Education have been favourably received. The aims of the Government in this context are regarded as generally sound. The policy which was set out in the White Paper was dictated by the country's economic needs, and the Government must by now be thoroughly aware that the effectiveness of that policy will be judged solely by the criterion of achievement. If the plans work out in practice and provide the technologists and technicians in sufficient numbers and of the requisite quality to enable Britain to maintain her position as a major industrial power, this Government will indeed be entitled to a considerable mead of praise. At this time, however, there is no room for half measures, for what is at stake is the status of Britain in this second Industrial Revolution, in which a number of technologies, including chemical engineering, will be tremendously important.

To make the paper plans work the Government must enlist the active co-operation of parents, teachers and industrialists. This point is stressed in the carefully considered memorandum on the White Paper which the F.B.I. has issued. The Federation urges its members to support the proposals, but it is pressing the Government to give more specific details of its intentions. For instance, it asks the Government to state how soon the proposed increases in the output of technologists and technicians will materialise. Again, it welcomes the proposed expansion of the day-release scheme, but the F.B.I. wants to know what time limit the Government will set itself for the doubling of the number of day-release students which is advocated. Many more teachers will be required in the technological field, and the F.B.I. quite rightly points out that plans for recruiting and training them are every bit as important as the capital investment plans.

More detailed criticisms of the White Paper were made in the House of Commons debate of June 21, and the result was that a certain amount of detailed information was elicited from the Government spokesmen. With regard to the £70 million building programme it emerged that the allocation of about £40 million for specific building projects has already been approved by the Minister, or is about to be approved. All of these projects will be under way by 1959. The 1959-60 building programme should be drawn up and approved next spring. Sir David Eccles named eight institutions which he intends to designate as colleges of advanced technology. These are Birmingham College of Technology, Bradford Technical College, Cardiff College of Technology, Loughborough College of Technology, Salford Royal Technical College, and in London, the Battersea, Chelsea and Northampton Polytechnics. This list means that certain parts of Britain are not yet covered by the Government's plans. At least one college of advanced technology is needed to provide for the growing industries of Tyneside and Tees-side, but in line with the general procedure favoured by the Minister it will be left to the local people to decide which college would be promoted to the "advanced" status. There is another gap, in the south-west, and Bristol College of Technology is the most likely choice here.

When the White Paper was issued the national press seized on the passage which referred to the possibility of recruiting more girls for training as technologists and technicians, and indeed most newspapers gave more prominence to it than to anything else in the document. The F.B.I. has now redressed the balance somewhat by reminding the Ministry of Education that employers are naturally reluctant to invest large sums on the long-term training of girls whose careers in industry tend to be short. The possibility of training more girls as technicians and technologists is worth detailed consideration, for there is no doubt that many of them are capable of being trained in technological subjects. In the chemical field the Royal Institute of Chemistry should soon be in a position to provide valuable information that will be relevant to this approach to the technological manpower problem. According to the chairman of the Committee on Scientific Manpower, Sir Solly Zuckerman, women account for 25% of Russia's engineering graduates, but it would be helpful if his committee could find out what percentage of practising engineers in the Soviet Union are women. One school of thought suggests that we should copy everything the Russians or the Americans are doing in technological education, but we agree with the president of the Institution of Chemical Engineers that it is best for Britain to work out her own solution for the shortage of technical personnel.

What we ought to try to learn from America is how to attract technologists to our shores and how to keep them here. At the moment Britain produces around 450 qualified chemical engineers a year as against the U.S. output of about 4500. We cannot afford to lose any of this talent to North America, and yet we are continuosly losing chemical engineers to the U.S.A. and Canada. This matter is one which deserves immediate investigation, for the nation loses more than it gains through this kind of emigration.

THE PURIFICATION OF

A factor limiting industrial and agricultural development in many countries is the shortage of fresh water. The various techniques of distillation that can be used to meet this problem are evaluated

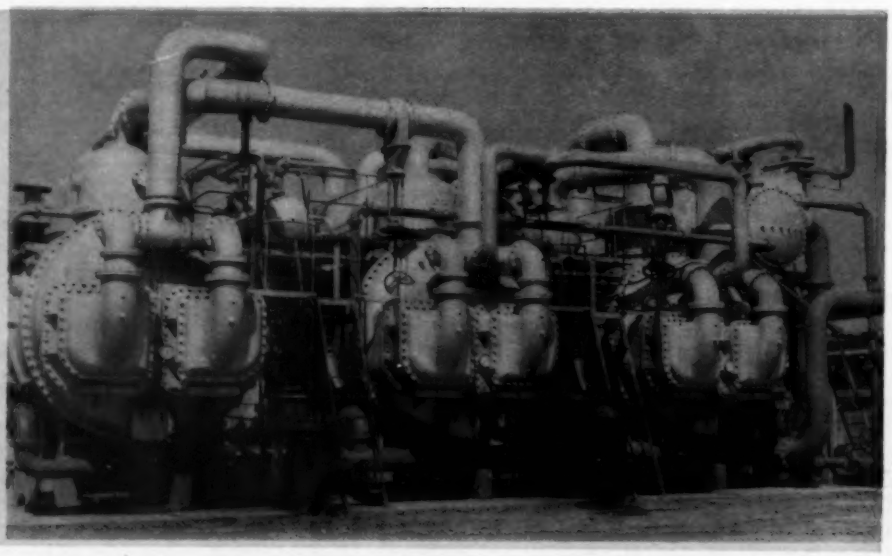
by J. LEICESTER, M.I.Chem.E., A.I.Mar.E.*

WITH the rise in living standards and the increasing industrialisation in many countries, the problem of finding enough fresh water to meet all needs is becoming ever more difficult. The problem is being actively tackled in the U.S.A. and throughout Europe, a fact which is reflected in the recent publication of several authoritative papers on the subject.[1–7] Awareness of the problem as it affects the British Commonwealth is growing, and it is widely realised how development schemes for individual Commonwealth countries can be hampered because only brackish or salt water is available to a particular community. Europe as a whole requires an expanding supply of fresh water, and Britain is no exception to this generalisation—indeed within the past few months a grave temporary water shortage was experienced in some industrial areas, for example around Liverpool, and water rationing had to be imposed upon a number of factories. In many coastal areas the drain on underground water supplies is such that water-bearing formations are not kept fully charged by percolating rain, which makes it possible for sea water to infiltrate; the result is that well water, for example, may become brackish and unsuitable for certain industrial purposes.

In a different category fall the water shortage difficulties of the arid regions, which present problems of increasing urgency. Their solution is to be regarded as an international task of the greatest importance. If fresh water can be made available to these regions, it could have a beneficial and stabilising influence.

What will be the position confronting us in twenty years time as population and industry alike expand? That it may be most critical has been realised for some time. This awareness of the risk of serious water shortages in Europe prompted the establishing of an international Working Party under the auspices of the Organisation for European Economic Co-operation, to sponsor co-operative research into economic methods for the de-salting of brackish or salt water. The Department of Scientific and Industrial Research is the Government department in this country responsible for co-ordinating the study of various methods of water purification, whilst the Admiralty are specifically responsible for research and development in the field of distillation techniques. In a similar manner, Holland is responsible for work on electrodialysis, Germany and France for ion exchange, and France for

*Director of Research, British Launderers' Research Association, Hill View Gardens, Hendon, London, and late Head of Chemical Engineering Division, Admiralty Materials Laboratory.



Weir triple-effect horizontal sea-water distilling equipment at the Aden Refinery of British Petroleum Co. Ltd. This plant provides 134,000 gallons of fresh water a day from sea water for the boilers of the refinery power station.

SALINE WATERS

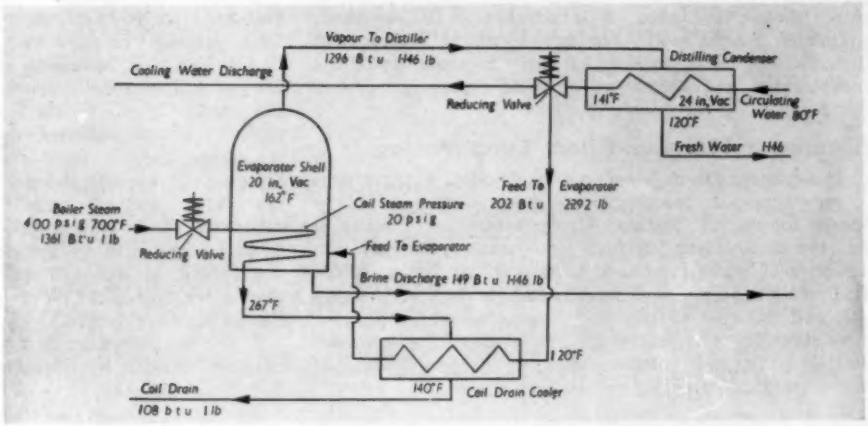


Fig. 1. Flow diagram of a typical single-effect distillation plant.

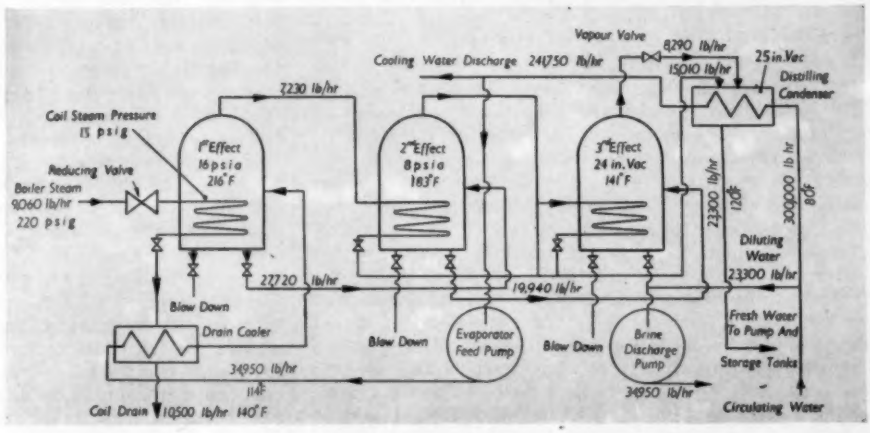


Fig. 2. Flow diagram of a typical triple-effect distillation plant. This particular unit is capable of delivering 2330 gallons an hour.

methods involving the use of solar energy. Independent work is also in progress in South Africa and in Israel. A similar co-operative project is in progress in the United States of America under the Saline Water Conversion Programme sponsored by the U.S. Department of the Interior.

Any method of water purification must either remove the soluble and insoluble salts from the water, or the water from the brackish or salty liquor, and on this basis can be regarded as a typical chemical engineering unit operation. In this article some of these methods will be considered in detail, and an attempt will be made to evaluate their economy.

The Magnitude of the Problem

In Britain the average consumption per head is of the order of 1500 gallons per day, if one includes agricultural, industrial and domestic requirements. For a population of fifty-five million, this means a total daily consumption of about 82,500 million gallons. The approximate cost of water used for the different purposes is as follows: 0.8d. per 1000 gallons for irrigation, 2.2s per 1000 gallons for domestic needs and 1.5s. per 1000 gallons for industrial usage. These figures provide a very rough guide as to the cost level, affording the basis for comparison when considering the economics of processes for de-salting brackish or salt water.

For undeveloped areas, the above costs might be multiplied by a factor of ten and still justify consideration of the possibility of installing water purification plant. A summary of the various promising methods of de-salting is given in Table I, together with an estimate of the probable cost per 1000 gallons of water produced.

Evaporation Techniques

When considering processes involving the purification of water by evaporation and re-condensation of the vapour, it is obvious that the operating locality can greatly influence the type of plant and ultimate cost of water produced. For instance, if a development scheme is considered which envisages the use of steam and cooling water as part of a major process plant, then obviously it would be prudent to use any available process or pass-out steam in some form of multi-effect or flash-type evaporator plant.

If, however, a situation arose where steam and cooling water were not available in sufficient quantity to support a development scheme, then consideration would have to be given to the self-contained diesel-driven vapour compression evaporator which requires no external source of heat or cooling water. The climatic and geographical conditions of the development area being considered may make solar evaporation an attractive method, alternatively they may favour evaporation processes based upon thermal differences either in the sea or inland lakes. All these factors must be assessed before it is possible to decide which particular process might best suit a specific development area. It will be of interest to study in more detail the technicalities and economics of these various processes.[8]

Single- or Multiple-Effect Evaporation

The evaporation of water in a single-effect evaporator is a very simple technical process, but unfortunately as a means for the purification of large quantities of water, it has the disadvantage of high heat consumption per unit quantity of water produced. Even with the lowest priced fuel, using the heat on a once-through basis is very wasteful, and the cost of the made water would be high. A flow sheet for a typical single-effect evaporator is shown in Fig. 1. The only methods likely to cheapen the cost of water produced from a single-effect evaporator are:

(a) The promotion of dropwise condensation on the condensing heat transfer surfaces;

(b) The production of thin turbulent liquid films over the evaporating heat transfer surfaces; and

(c) The use of small temperature differences between heating steam and evaporating liquid as a means of reducing fouling of the heat transfer surfaces.

Experimental work at present in progress in the Admiralty as part of a joint Anglo-Dutch co-operative project is showing considerable promise, and may well result in the design of an evaporator which will be capable of handling high solid content brackish waters and sea water without the associated loss in efficiency due to the fouling of the heat transfer surfaces. It is estimated that by means of a combination of these techniques it should be possible to produce fresh water from sea water at a total cost of approximately 60s. per 1000 gallons. This assumes costs for steam, cooling water, depreciation, operating charges, insurance, etc., as is indicated in Table I, and an investment cost of £10,000 for a 2500 gallons per hour unit. Present costs would be about 100s. per 1000 gallons.

The use of a multi-effect evaporator provides a much more economical process for the large-scale evaporation of water. Whilst the single-effect evaporator degrades the heat supplied by only a few degrees, the use of more than one effect enables the heat to be successively re-used in effects operating at lower temperatures. A typical triple-effect evaporating plant is illustrated by the flow sheet given in Fig. 2. In this type of unit, heat requirements per unit quantity of water evaporated are less, but plant investment costs are higher. The optimum number of effects will depend upon the total solid content of the raw water to be evaporated. For sea water, this would appear to be a sextuple-effect plant. The earlier mention of work on dropwise condensation, liquid film turbulence and reduced fouling coefficients applies equally to the multiple-effect evaporator. It may be possible to obtain heat transfer coefficients in the region of 3000 Btu's/hr (sq. ft). °F, and with the subsequent ability to use lower temperature differences between heating steam and evaporating liquor, the operating costs would be considerably reduced. Calculations for a typical sextuple-effect evaporator handling sea water show that a probable cost for the production of fresh water would be in the region of 20s. per 1000 gallons. Again, similar costs are assumed for steam, cooling water, depreciation, labour, operating charges, insurance, etc. and an investment cost of £50,000 for a 10,000 gallons per hour unit. This compares with a present cost of 28s. per 1000 gallons.

Multiple Stage Flash-Type Distillation

The principle of flash distillation is not new, but when fuel costs are of the utmost importance and the cost of water produced must be low, then this method of distillation becomes of increasing interest. In conventional submerged coil or tube evaporators, there are limitations to the number of effects which can be incorporated, and the total temperature difference between condensing steam and the temperature of the vapour in the last effect is fixed by practical considerations. Furthermore, in the conventional evaporator heat transfer is a function of temperature difference, and with small temperature differences per effect losses due to hydrostatic head become of increasing importance. It is not therefore possible to justify more than a sextuple-effect plant, and more often only two or three effects are used.

In the multiple-stage flash-type plant, there are no comparable losses in heat transfer with reduced temperature differences per stage, and no heat losses due to hydrostatic head. If fuel were the most important operating cost, then with this type of evaporator it should be possible to use very small temperature differences per stage. However, in practice, total cost is balanced against fuel cost when deciding on the optimum number of stages. In general, the number of these stages is greater than the number of effects in a submerged coil plant, and the corresponding fuel consumption is less. It is desirable to operate the final stages in this type of plant at very low absolute pressures, and this in turn means large vapour volumes and the necessity for very efficient moisture entrainment separators to be fitted in the vapour off-take.

Fig. 4 is a flow sheet of a 1700 gallons/hr five-stage flash-type distilling plant manufactured by the Griscolm Russell Company of U.S.A. This design of unit is very compact for its capacity, and it comprises a number of built-in stage condensers for handling the vapour flashed from each effect. The incoming feed water is used as the condensing medium. This unit operates at a high vacuum (0.6 inches of mercury absolute pressure with 32°F feed water), and throughout the cycle salt water temperatures and temperature differences are in the low region where scale deposits are at a minimum. Brine concentration is approximately 1.1 times that of the incoming salt water, and this low value also greatly reduces the tendency to solid deposits on the heating tube surfaces. The external salt water heater carries the highest temperature, and this is limited to around 170°F.

It will be seen from the flow diagram (Fig. 4) that the plant uses 0.286 lb steam per lb of fresh water made, and together with the steam required to operate the air ejectors, results in an over-all performance of 3.2 lb. of distillate per lb of steam supplied. In terms of fuel economy, operating in conjunction with a steam turbine power plant, this represents a figure of approximately 150 lb of distillate per lb of fuel burned in the boiler. However, if the equipment were considered as a packaged unit complete with its own small steam generator, then this value would drop to around 60 lb of distillate per lb of fuel. In terms of cost this would be approximately 20s. per 1000 gallons for an integrated power plant installation, and 27s. per 1000 gallons for a self-contained evaporator and boiler unit. Similar operating costs as before are assumed and a plant investment of £20,000 for a 2000 gph unit.

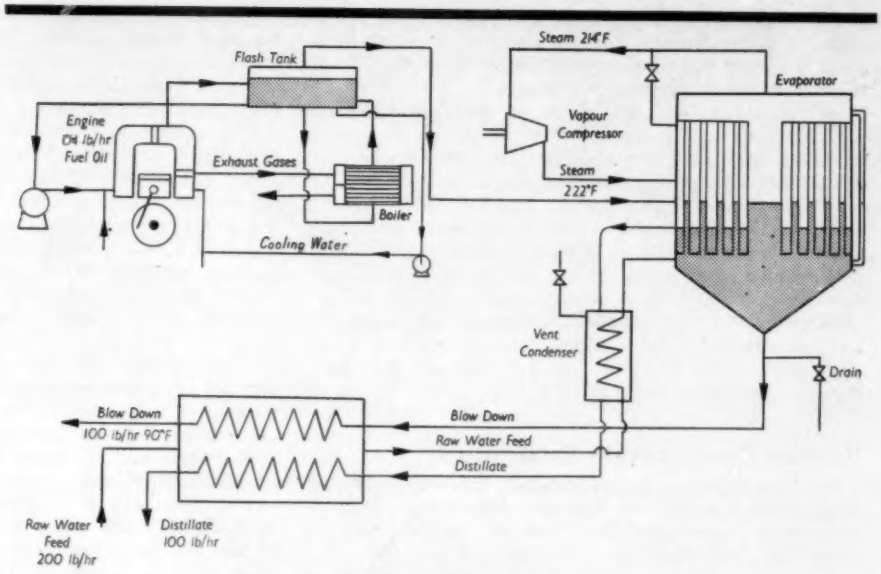


Fig. 3. Flow diagram of diesel-driven vapour re-compression evaporator with output of 250 gallons an hour. (Mechanical Equipment Corporation, U.S.A.)

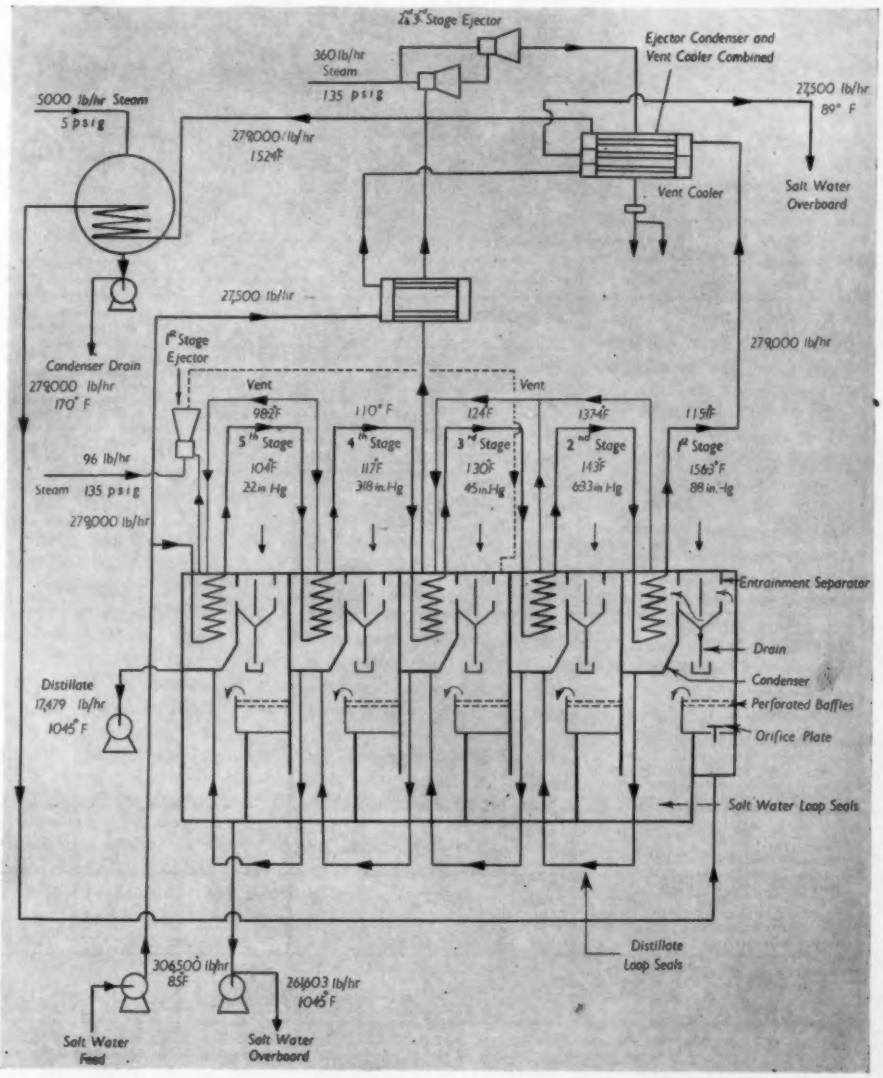


Fig. 4. Flow diagram of 5-stage flash-type distillation plant (Griscom-Russell Co., U.S.A.)

Future development plans for this type of evaporator envisage larger units having a capacity of 30,000 and 170,000 gallons per hour respectively. It is estimated that these units would produce 5 lb and 6 lb of distillate per lb of steam supplied. The latter unit would probably be a 10-effect plant. The application of the earlier mentioned work on dropwise condensation and fluid turbulence would also reduce operating costs and yield a lower price for the made water. The fuel economy for a unit working in conjunction with a power plant would be 234-281 lb of distillate per lb. of fuel; coupled to a packaged boiler, its performance figure would be approximately 94-112 lb. of distillate per lb of fuel. A probable cost would be 8s. per 1000 gallons for a power plant installation and 11.6s. per 1000 gallons for a unit complete with a packaged boiler installation. (The cost falls as the scale of the plant increases, as indicated in Table 1.)

Vapour Compression Distillation

We have seen that in the conventional evaporator, the major disadvantage is the high heat consumption per unit volume of water produced, and if high temperature differences are employed between heating steam and evaporating liquid, there would be a higher fouling rate of the heat transfer surfaces. Although numerous chemical feed additives have been developed which greatly minimise this effect,[8] no single treatment can yet be said to completely solve the problem.

The principle of vapour re-compression can, however, offer significant help in this direction, and with the application of certain of the techniques already mentioned, for example, low retention time, dropwise condensation and turbulent liquid films over the heat transfer surfaces, may yet go far towards providing one of the cheapest methods for the purification of brackish or salt water. The thermal cycle of this type of evaporator offers one of the most efficient methods at present in use as commercial equipment (Fig. 3).

Fundamentally the high fuel economy of this process depends upon the compression of the vapour leaving the evaporator compartment so that it can be used in the condenser-boiler heat exchanger in place of the more conventional process steam. In giving up the latent heat of condensation, the compressed vapour condenses, passes out of the plant via further heat exchangers and then becomes the made water product of the process. As will be seen, no large source of cooling water is required for

Table 1 — Possible Water Purification Methods and Future Estimated Cost Data

TECHNIQUE, PROCESS OR SOURCE OF WATER SUPPLY

Natural Water Supply: cost per 1,000 gal.

for Agriculture ... ... 0.8d.
for Industry ... ... 1.5s.
for Domestic use ... ... 2.2s.

COST DATA ASSUMED

1. Pumping costs of raw water — 4.5d. per 1,000 gal.
2. Condenser cooling or rinsing water — 2.3 shillings per 1,000 gal.
3. Fuel Oil cost — £7 10 shilings per ton.
4. Steam cost — 18 shillings per ton.
5. Electrical Power cost — 1d. per kWh.
6. Labour cost — £600 per man per year.
7. Plant maintenance — Varying between 6 and 8% of the investment charge according to the type of plant.
8. Depreciation — Repayment of the plant investment charge over periods varying between 10 and 15 years.
9. Overheads — 80% of the labour and and maintenance costs.

Cost per 1,000 gallons de-salted in shillings (inclusive of power, labour, maintenance, overheads, insurance, interest on working capital and depreciation costs).

DISTILLATION TECHNIQUES	Plant Capacity 2,500 gallons per day				Plant Capacity 250,000 gallons per day				Plant Capacity 1,000,000 gallons per day			
	De-Salting 5,000-500 ppm Range		De-salting 20,000-500 ppm Range		De-Salting 5,000-500 ppm Range		De-salting 20,000-500 ppm Range		De-Salting 5,000-500 ppm Range		De-Salting 20,000-500 ppm Range	
	Total Cost	Power Cost	Total Cost	Power Cost	Total Cost	Power Cost	Total Cost	Power Cost	Total Cost	Power Cost	Total Cost	Power Cost
Single Effect	134.0	70.0	136.0	70.0	100.0	70.0	103.0	70.0	80.0	70.0	83.0	70.0
Sextuple Effect	59.0	14.0	61.0	14.0	25.0	14.0	27.8	14.0	18.0	14.0	21.0	14.0
Multi Stage Flash Type	58.0	13.0	60.0	13.0	21.2	13.0	24.0	13.0	16.0	13.0	18.0	13.0
Vapour Recompression (Present costs)	46.0	2.5	48.0	2.5	10.6	2.5	11.0	2.5	8.0	2.5	8.6	2.5
(Future costs)	40.0	2.5	42.0	2.5	9.0	2.5	9.6	2.5	7.0	2.5	7.6	2.5
Critical Pressure (Von Platen Principle)	—	—	—	—	—	—	—	—	—	—	18.0	2.7
Solar Energy	34.5	—	35.5	—	24.0	—	25.0	—	15.0	—	16.0	—
Ocean Temperature Difference	—	—	—	—	—	—	—	—	17.0	9.0	17.0	9.0
ION EXCHANGE AND ELECTRODIALYSIS												
Conventional Ion Exchange†	—	—	—	—	—	—	—	—	—	—	—	—
Electrodialysis												
Present costs	39.0	5.0	70.7	30.0	16.2	5.0	44.0	30.0	13.9	5.0	42.9	30.0
Future costs assuming 25% reduction in membrane resistance and 50% reduction in plant costs	34.2	3.8	60.0	22.5	10.9	3.8	33.1	22.5	9.4	3.8	32.0	22.5
Long term future costs assuming 50% reduction in membrane resistance and 50% reduction in plant costs	33.1	2.5	52.6	15.0	10.1	2.5	25.6	15.0	8.3	2.5	24.7	15.0
Osmotic Techniques												
Reverse Osmosis	—	—	—	—	32.0	—	32.0	—	27.5	—	27.5	—
Pressure Osmosis*	—	—	—	—	—	—	—	—	—	—	—	—
FREEZING TECHNIQUES												
Conventional freezing combined with countercurrent washing	—	—	—	—	—	—	—	—	7.0	—	11.0	—
Zone Freezing	—	—	—	—	—	—	—	—	—	—	—	—
SOLVENT EXTRACTION TECHNIQUES												
Tentative estimate	—	—	—	—	12.0	0.25	12.0	0.25	10.0	1.0	10.0	1.0

** No reliable cost estimates yet available. † Uneconomical at salt levels above 1,000 ppm new techniques in regeneration may raise this level to 2,000 ppm. Costs not expected to drop below 15 shillings per 1,000 gallons.*

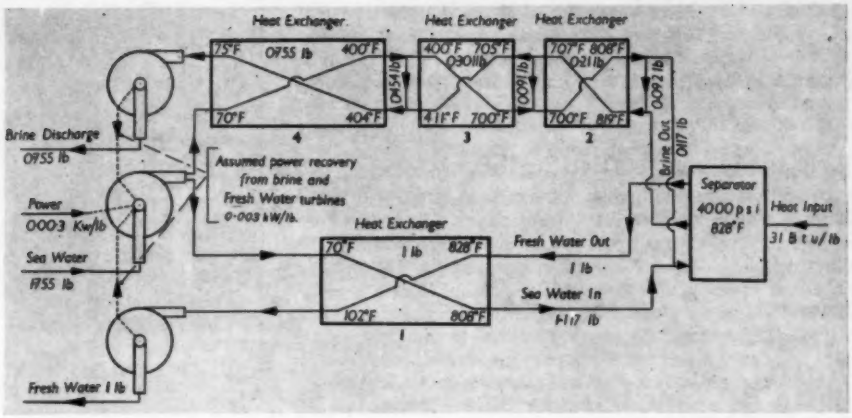


Fig. 5. Flow sheet illustrating the basic principles of critical pressure distillation.

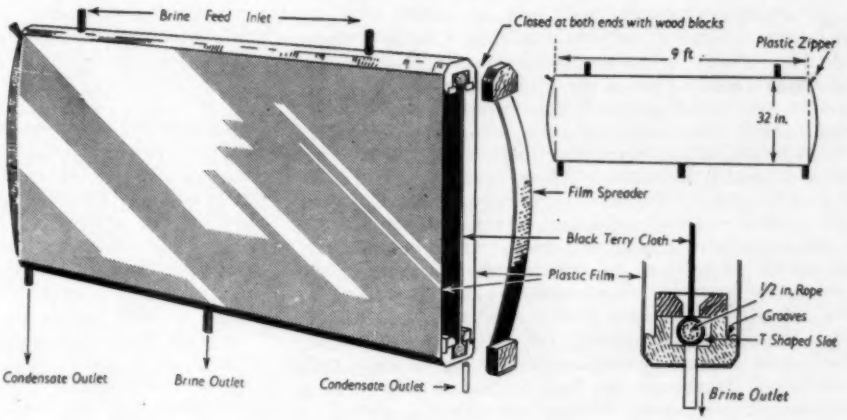


Fig. 6. A solar energy still in perspective and side elevation. The third diagram is a section through the brine outlet.

condensers, and once the unit has been brought up to boiling, the evaporator virtually "eats its own tail". In the case of direct diesel engine-driven units with exhaust waste heat exchangers, the unit can produce as much as 270 lb. of distilled water from sea water per lb. of diesel oil consumed by the engine. However, in existing units this performance can only be achieved with clean heating surfaces, and fouling in this type of unit can rapidly reduce the operating efficiency and, in act, force the plant to be shut down at frequent intervals for mechanical cleaning of the heat transfer surfaces.

It is in this type of evaporator, however, that I feel that spectacular improvements are likely to be achieved. Most of these plants operate with a temperature differential across the condenser/evaporator of around 15°F. This value is not low enough to reduce scale formation appreciably and, furthermore, it means the use of a steam compressor capable of raising the steam pressure by as much as 3-5 psi. To maintain the correct temperature differential in spite of scale formation requires energy in one form or another; hence power consumption by the compressor or auxiliary heaters is the major operating cost item. In the conventional vapour compression evaporator, no real attempt has been made to reduce the retention time of the brine, or to obtain highly turbulent liquid films over the heating surfaces or to promote dropwise condensation on the heat transfer surfaces. Much of our present experimental work is concerned with these three matters, and the results achieved to date are very encouraging. With such techniques, there is a good prospect that scale formation can be made negligible; with a small amount of chemical treatment, it may be completely prevented. In addition, due to the ability to work the plant with a much reduced temperature difference across the condenser-evaporator, power consumption of the compressor is greatly reduced and hence the major cost item of the process. In fact, the compressor now becomes more of a blower or high pressure fan, required to produce a pressure differential of only about 20 in. water gauge pressure. Very similar work to this has been reported by Hickman, of the Badger Manufacturing Company,[9] using a rotating heat transfer surface combined with the vapour recompression principle. This special arrangement secures freedom from fouling of the heat transfer surfaces and the production of thin turbulent liquid films, and these two factors combine to give a high thermodynamic efficiency; inevitably however the mechanical design has to be made more complicated (and therefore more expensive) than it is in the present vapour compression still. It is my opinion that these same beneficial results can be obtained from a unit of much simpler mechanical design. This would have other advantages such as easier operational performance and maintenance and also lower initial plant investment charges. From all this work it would appear that in the not-too-distant future, vapour recompression equipment will be produced that can provide fresh water from sea water at a total cost of aproximately 9.5s. per 1000 gallons. This assumes costs for diesel oil, depreciation, operating charges, insurance, etc., as shown at the top of Table 1, and an investment cost of £100,000 for a 10,000 gallon per hour plant. Present design commercial equipment can already produce water for costs approaching 11 to 12s. per 1000 gallons.

Available data shows that vapour recompression tech-

niques provide a real challenge to electrodialysis and that even assuming considerable development of this latter technique vapour recompression may well be the most economical method of de-salting water containing more than 5000 ppm Cl content.

Critical Pressure Distillation

Work on this method is currently in progress in the laboratories of the Nuclear Development Corporation of America,[10] and forms a part of the U.S. Department of the Interior Saline Water Conversion Programme. The process is based upon the original idea of Von Platen, and is illustrated schematically in the flow diagram given in Fig. 5. The method depends upon raising the pressure of the sea water above the critical pressure of pure water when, on further heating, separation takes place into a salt-rich liquor and an essentially salt-free vapour phase. The heat required to effect this separation will obviously be much less than the heat required to effect separation in a normal evaporator due to the low enthalpy of vaporisation and recovery of sensible heat. The two phases would be drawn off separately and returned to the heat exchangers where most of the sensible heat would be given up to the incoming feed water. After leaving the heat exchangers, both waste streams would be discharged through turbines to recover a major proportion of the work expended in pumping the sea water up to near the critical pressure. Pilot plant experiments have established the feasibility of the separation process, and tentative cost estimates have indicated that fresh water could be produced for about 14s. per 1000 gallons. However, major difficulties that would be encountered with this method are the corrosion of the materials of construction at the very high pressures and temperatures of operation, necessitating the use of titanium of titanium alloys, and secondly, scale formation throughout the heat exchangers. This latter problem is particularly vicious, and unless a method of scale prevention can be developed the complete project is likely to fail. It is not considered that this work offers anything like the feasibility of the various methods of vapour recompression evaporation or multi-stage flash evaporation.

Solar Distillation

Whilst distillation using solar energy as the source of heat is not likely to be of interest to Britain, nevertheless it may offer possibilities for certain of the Commonwealth countries. The major proportion of the development work on this type of equipment is being carried out in the U.S.A.[11] and by the French in Algeria and Tunisia.[12] Studies carried out over the past few years have indicated that the use of solar heat in equipment of simple design offers the best chance of producing fresh water from salt or brackish water at the lowest over-all costs. Due to the low grade heat available, the size of solar distillation equipment is bound to be large, and hence investment charges will be the major cost item in this process. It is therefore esesntial that any equipment designed must be of the utmost simplicity and must be fabricated from materials of construction that are themselves low in cost. The basic process in itself is quite old, and one installation capable of producing up to 6000 gallons per day of fresh water was in use in South America as early as 1872. These units had sloping glass plates that allowed the sunlight to pass through and to be absorbed by the brackish water. The water vapour formed condensed on the underside of the glass plates and drained down to a collection trough. This early unit had a glass area of some 50,000 sq. ft for the output of 5000 gallons per day. Developments during recent

The solar still at Cohasset, Mass. Covering an area of 200 square feet, this has a maximum daily water production of 1.2 pound per square feet in the month of August.

years have been concerned with the use of plastics materials for low constructional cost and various methods of improving the heat transfer between the energy source and evaporating water. The work being carried out by Telkes & Bjorksten has used a black porous media saturated with the salt or brackish water as a means of improving the heat absorption rate. Terry towelling dyed black has also been used, although recent work has shown that extruded synthetic fibres, naturally coloured with a finely divided black pigment, can be woven into a suitable cloth. This material has much improved resistance to weathering. Solar stills constructed from plastics materials may find their greatest value in relatively small unit equipment for the supply of say up to 1000 gallons per day of fresh water (Fig. 6). Pilot plant trials have indicated that fresh water from sea water could be produced for around 34s. per 1000 gallons, with the proviso that a cheap plastics sheeting can be developed which will withstand weathering for at least three years.

Other designs, based upon an entirely different approach, offer interesting possibiiities. Here, the distiller is of concrete, built directly on the ground and without the usual bottom insulation. The basin so formed may contain up to 1 ft depth of water rather than the shallow depth used in the older type of equipment. The large basin is sub-divided into a series of smaller basins by means of precast concrete curbs which also provide the support for the glass covers and condensate troughs. The glass covers are sloped at a low angle (10°) up to a central ridge support, rather than at the more conventional 45° angle of slope. The compartments are so arranged that heat exchange can be obtained between the incoming and outgoing liquid streams. This design offers considerable advantages for a large-scale unit, and construction costs should be quite low. The materials of construction used—glass, concrete and plastics tubing—should all be capable of withstanding long periods of exposure with the minimum of deterioration. Due to the greater depth of water in the basins, a temperature smoothing effect will be obtained which should enable the unit to operate day and night without appreciable changes in the distillation rate. Hence continuous operation permits a reduction in the glass condenser area, and also allows the use of the 10° angle of slope. From design calculations, it is anticipated that this type of unit will be capable of producing at least 5000 gallons of distilled water per day from an approximate surface area of 40,000 sq. ft, and at a cost of about 17s. per 1000 gallons.

Solar stills were discussed at the World Symposium on Applied Solar Energy (1955), the proceedings of which have been published by Stanford Research Institute, Menlo Park, California.

Distillation Using Temperature Differences in Large Water Masses

Several investigators have been examining the possibility of using the temperature differential in the ocean, large inland lakes or impounding reservoirs. This work again is dependent to a large extent upon harnessing the sun's energy, and is of most interest to territories outside Britain. Normally, temperature differences in the ocean or deep lakes are associated with considerable differences in depth, and hence the vast quantities of water which would have to be pumped from these depths makes the process inoperable. However, recent work by Tabor,[13] might make the process worth consideration. The aim has been to increase the surface temperature—probably in a shallow lagoon or lake—by means of surface films floating on the water to prevent heat losses by convection. This early work, using a surface film of oil, has not proved satisfactory and a suggestion by Block[14] that a density gradient could be set up by floating a layer of fresh water on a layer of brine has been followed up with much more success. Such a density gradient would be extremely stable, and would prevent the setting up of convection currents. The fresh water on the surface would be relatively transparent to any infra-red radiation which would then be absorbed as the brine concentration increased. Below a certain depth all the infra-red would be absorbed and the temperature would then fall off rapidly. It is claimed that temperature differences of 120°F or more could be achieved with relatively small differences in the depth of the water. The method seems most ingenious and although at the moment no cost estimates are available, the development should be watched with interest.

Summarising the Processes

Summarising the various distillation processes, it can be said that the one offering the most attractive future possibility for the economic production of fresh water from salt or brackish water is vapour recompression, combined with the latest developments in dropwise condensation, turbulent liquid films and low retention times. These units could be designed as a small, self-contained, packaged plant, readily available for the small consumer and capable of easy location at any particular site. The units could be mobile, the diesel engine power unit being used either for transportation or for running the distillation unit. For supplying greater quantities of water to a variety of consumers, the installation might consist of a number of these units located in some centralised position and more or less erected as a permanent installation. In this latter case, consideration should also be given to the possible use of one large steam compressor serving a number of evaporator-condenser units. In this case, compressor costs would be reduced and the layout would enable the design of a more efficient steam compressor of the axial flow type. It is considered that such evaporators would be capable of supplying water at a total cost of between 9 and 11s. per 1000 gallons according to the size of the installation.

If waste steam or heat is available as a by-product from some other source, then in such a location consideration must be given to multiple-effect or flash-type distillation units, again incorporating the latest findings on heat transfer, turbulent liquid films and low retention times. Such multiple-effect conventional evaporator installations could be expected to produce fresh water for approximately 20s. per 1000 gallons, and a flash-type distillation unit for approximately 15s. per 1000 gallons. Future development of a 10-effect flash distillation unit may well reduce the cost to as low as 8 to 9s. for 1000 gallons. The expected improvements in evaporator performance also make the small single-effect evaporator of interest to isolated areas, where steam might be produced in small portable boilers burning local waste, such as wood waste, maize cobs, coconut shells, etc., as a source of cheap fuel. Here, one can envisage a very low cost for the water produced.

With regard to the other methods discussed, solar energy offers possibilities for certain arid regions of the world where unlimited solar energy is available, although considerable development of equipment has yet to be undertaken. Distillation at the critical pressure, although offering promise of low heat energy requirements, is beset by real difficulties in the materials of construction required to withstand the vicious corrosion throughout the cycle, and also the very heavy fouling of heat exchanger equipment. It is not thought that this process is likely to offer any serious challenge to the various designs of vapour recompression or multi-effect evaporators.

Distillation using temperature differences in lakes or lagoons is not yet far enough advanced to offer any real assessment as to its potentialities. It is certainly going to be limited to specific areas of the world, and at the moment costs are problematical.

Finally, although not discussed as an actual project, the summary would be incomplete without referring to the possible impact of atomic energy on distillation processes. Should the present development of atomic power plants lead to the colonisation and industrial development of areas that are at the moment scarcely or completely unpopulated, then undoubtedly in the course of power generation and supply, low grade heat would be available in large quantities. The techniques discussed in vapour recompression and single- and multiple-effect evaporation are all aimed at the use of heat at increasingly low levels, and hence they would lend themselves well to integration into an atomic power station cycle. Such developments might well translate into practical terms the vision of turning the arid waste and desert areas into a land flowing with milk and honey.

(In the next issue the author will discuss the potentialities of other techniques for producing fresh water, including ion exchange and electrodialysis.)

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(The second half of this article, which discusses ion-exchange and electrodialysis methods, will be published in our next issue.)

The final article in this series gives the salient features of some industrial gas separation processes and shows how the principles described in the earlier articles (published in our June and July issues) are applied

PRINCIPLES

by N. W. ROBERTS, M.A., F.R.I.C.

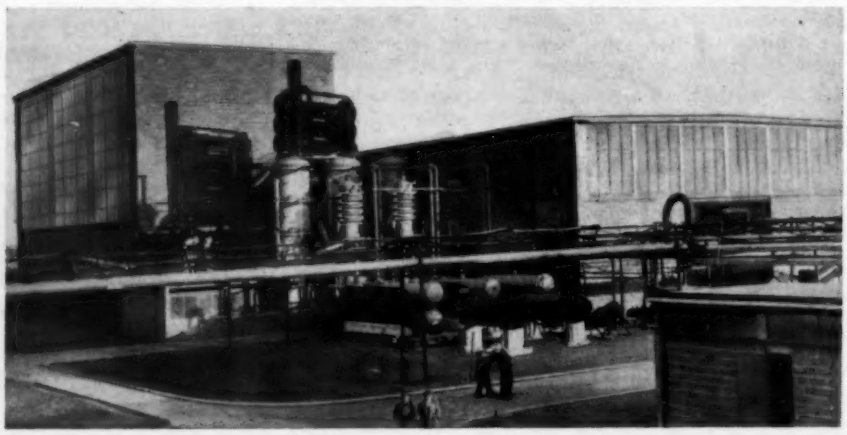
THE first process for separating air at low temperatures was patented by Linde in 1902. The idea was to find a cheaper way of making oxygen, which up to that time had been made by the Brin process (based on barium peroxide). It had the simplest possible distillation column, as shown in Fig. 1. The column consisted only of a stripping section; since there was no rectification, the nitrogen was rather impure and the yield of oxygen was consequently low.

Compressed air was cooled in a heat exchanger, and liquefied in a coil immersed in the liquid oxygen sump at the bottom of the column. The liquid was then expanded through a valve into the top of the column where it acted as reflux to scrub the vapours rising from the sump until the oxygen content of the waste nitrogen product was reduced to about 8%. Similar systems are used to this day on very small oxygen plants, where the relatively high heat losses make it necessary to keep the equipment as small and as simple as possible.

The low yield due to the lack of rectification provided a powerful incentive to improvement. The obvious suggestion was to take the produced nitrogen after warming and compress a part of it. After cooling by heat exchange and liquefaction in a coil the nitrogen could be used as reflux and could nearly double the yield of oxygen. Technical difficulties befell this scheme, and nearly fifty years had to pass before advances in the technique made its application in the Rescol process possible.

It again fell to Linde to increase the yield of oxygen to its practicable limit through the invention of the double column. This is a unique device, which owes its success to the fact that the oxygen content of the air is no more than 21%, and to the conveniently high relative volatility of nitrogen and oxygen. The double column is illustrated in Fig. 2. Air at 5 atm. absolute, having been pre-cooled by heat exchange and refrigeration, is admitted to the lower column. The pressure is sufficient to liquefy pure nitrogen in a condenser. This is cooled by the liquid oxygen in the sump of the upper column which operates at atmospheric pressure. The nitrogen so liquefied can be used as reflux to bring about a partial separation of the air—by rectification without stripping—into a pure liquid nitrogen fraction and a liquid somewhat enriched in oxygen.

When these two liquid fractions are expanded through valves to the appropriate points in the upper column, it can be seen that all the conditions for a complete separation are satisfied. There is a pure nitrogen reflux (which is more than the minimum); a liquid feed; and a boil-up, which again is sufficient to allow the extraction of 21% of oxygen from the air, although it would not be adequate to extract much more.



Gas separation plant at Petrochemicals Ltd., Urmston, Manchester. This plant employs cascade refrigeration for liquefaction of gases followed by low-temperature fractional distillation.

OF GAS SEPARATION—Part 3

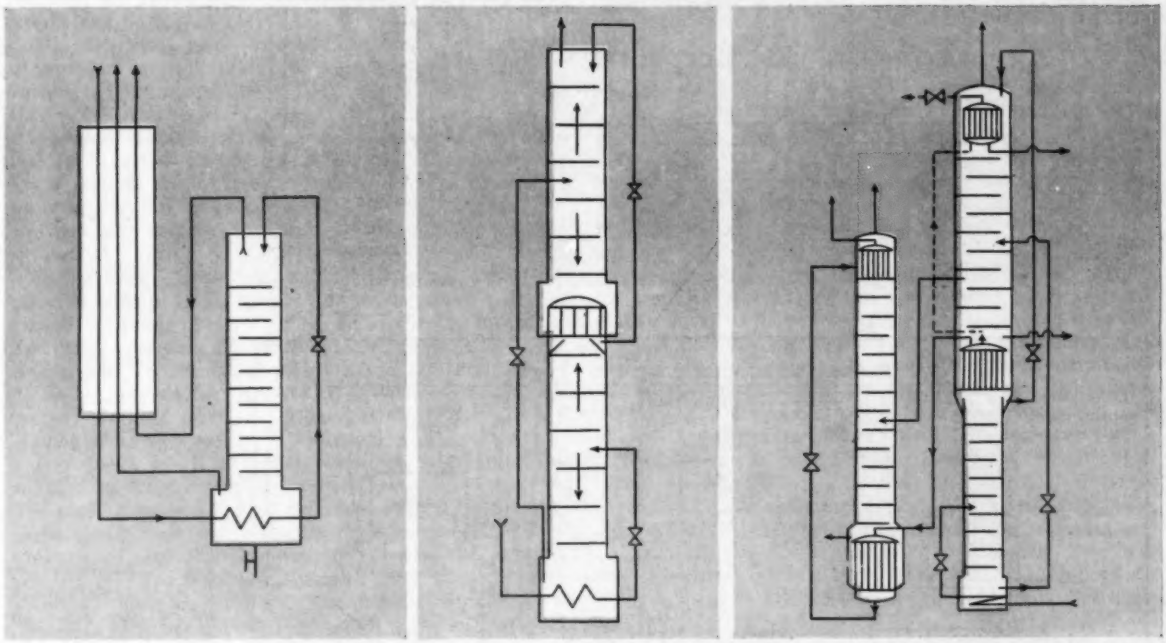


Fig. 1 (*left*). *Simple Linde air column. Fig.* 2 (*centre*). *Diagram of Linde double air column. Fig.* 3 (*right*). *Flow diagram showing argon column combined with Linde double air column.* (*After Ruhemann, "The Separation of Gases," O.U.P.,* 1940.)

But even so, the yield of pure oxygen from a double column was limited to about 19% of the volume of air fed to the column. The cause was argon. There is less than 1% of argon in air, but that small proportion plays a major role in air distillation techniques; it can never be neglected. The reason is that the boiling point of argon lies between those of oxygen and nitrogen. The effect of the nitrogen reflux, since the argon is less volatile, is to force it downwards, while at the same time, since the argon is more volatile than the oxygen, it is being forced upwards from that end. The combined effect is to create a marked rise in argon concentration in the middle of the column, which impedes the separation of oxygen and nitrogen. In the simple double column as shown in Fig. 2, the argon must go out with one or the other of the products. And if the oxygen is to be 99.8% pure, it must go out with the nitrogen, so that unavoidably some oxygen must be lost in the nitrogen stream.

There are two ways of dealing with this problem. One can take the argon out in the middle of the column, either to work it up to a pure saleable product, or with the sole object of making possible the simultaneous manufacture of pure oxygen and pure nitrogen; alternatively one can manufacture *medium purity oxygen* in which the majority of the argon is withdrawn with the oxygen product. Each method has a well-defined sphere of application. The first has grown in popularity under the stimulus of the demand for argon for argonarc-welding purposes which has arisen in the post-war years. The manufacture of medium purity oxygen, confined to Germany in the thirties, has become general with the realisation of its economic advantages in the metallurgical and process industries.

Separation of Rare Gases

When an air separation plant is adapted for the simultaneous manufacture of argon, it is often found that the other rare gases are extracted at the same time. One method by which this can be accomplished is illustrated in Fig. 3. This shows the column system used.

Pre-cooled air is liquefied in a coil in the base of the lower column, and expanded through a valve into the column. There it is separated as previously described into a pure liquid nitrogen fraction and another fraction somewhat enriched in oxygen. In this case, however, not all of the air is liquefied in the condenser at the top of the lower column, a portion being withdrawn as shown to act as a means of reflux in the subsidiary argon column, as will be described. The separated liquid fractions produced in the lower column are expanded from the pressure of 5 atm. at which they are formed to substantially atmospheric pressure and fed at the proper points into the upper column. Meanwhile, a small proportion of the gas

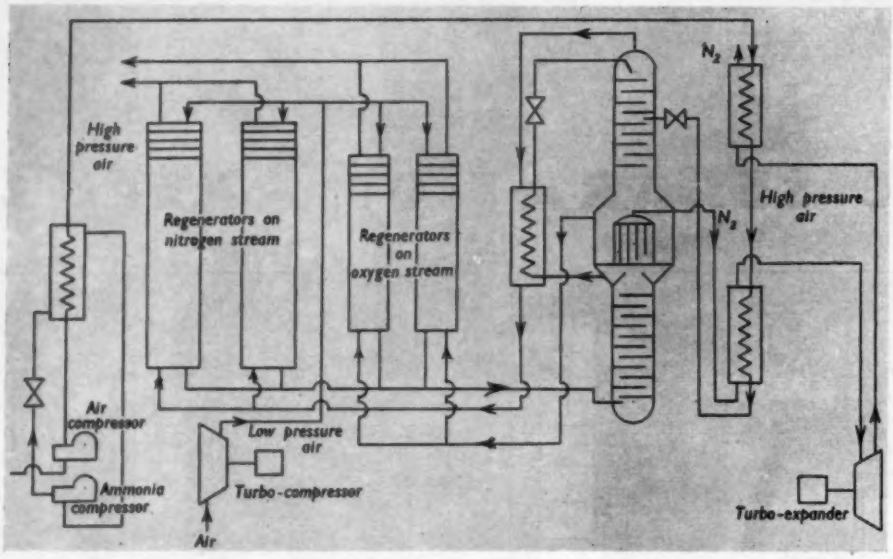


Fig. 4. Flow diagram of Linde-Fränkl plant for 98% gaseous oxygen plant, showing two pairs of generators.

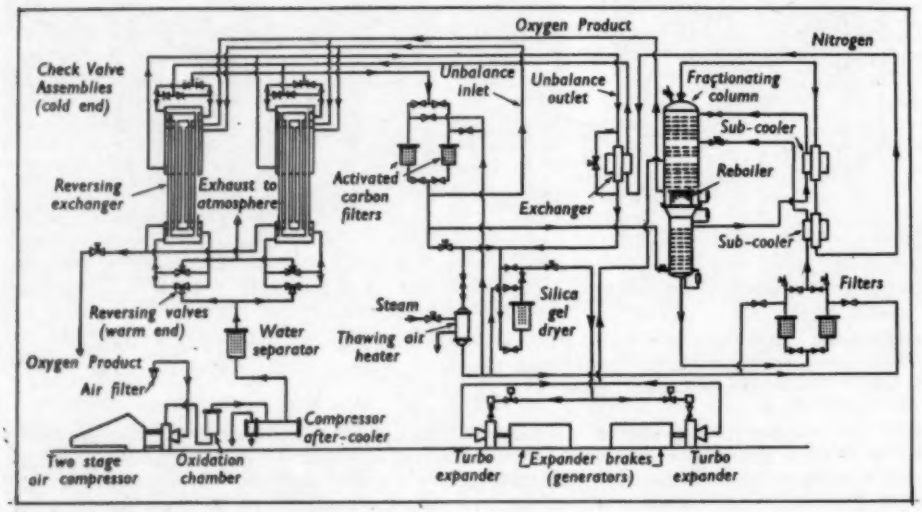


Fig. 5. Flowsheet of Kellogg oxygen plant, which uses reversing heat exchangers with balancing air.

from the condenser is bled off, still under its pressure of 5 atm., and cooled by the liquid nitrogen reflux. Since the neon and helium which are contained in the air are not condensible at the temperature of liquid nitrogen, the gas which emerges from this treatment consists of a mixture containing 70-80% of neon and helium with only the remainder nitrogen. It should be noted in passing that the condenser at the top of the lower column must be vented in this way even if the neon and helium are not to be recovered, otherwise the non-condensibles would impair its operation in the same way that air impairs the operation of steam-using apparatus.

In the upper column the liquid fractions are separated into oxygen and nitrogen fractions, but the difficulties with argon are reduced by the withdrawal at a suitable point of an argon-rich fraction, which is fed to the subsidiary argon column. With careful attention to the placing of the various feed and withdrawal points, it can be arranged that this fraction consists of a mixture of oxygen and argon only, the nitrogen being completely eliminated owing to its greater volatility. In the subsidiary argon column, boil-up is provided by the condensation of the gaseous nitrogen at 5 atm. already referred to, while the condensate is expanded to atmospheric pressure and re-evaporated in a condenser at the head of the column, thus providing a sufficient reflux to separate the side-stream into substantially pure argon and oxygen fractions. It is usually necessary to purify the argon further by chemical means before it is fit for sale.

In the system described, the fact of the withdrawal of a part of the nitrogen produced in the lower column to act as reflux in the argon column means that there is a shortage of reflux in the main column, which makes the yield of such a system slightly lower than that of the ordinary double column; but this is more than compensated for by the yield of a very valuable product so obtained. The fact that it is possible to withdraw such a fraction without serious detriment to the operation of the double column is used to great advantage in the Linde-Fränkl system, which was the first type of medium purity oxygen plant to be developed. It was also the first type of plant to use regenerators. It is illustrated in Fig. 4.

As described in the second article in this series, regenerators are used in pairs. In the present case two pairs are required, one pair operating on oxygen, and one on nitrogen. Of each pair at a given moment, one is being cooled by the products of the separation while the other is giving up its store of cold to the incoming gas. After some minutes, an automatic valve system changes over the functions of the pair of regenerators, so that each may be considered as oscillating about a position of equilibrium. The amplitude of the oscillations is small, so that for most purposes the regenerators may be considered to be in a steady state.

The air, then, after compression to 5.5 atm. in the compressor is split into two portions, corresponding roughly in volume to the oxygen and nitrogen fractions into which it is to be separated, and these portions pass respectively through one regenerator of each pair. Here the air is cooled almost to saturation, and fed into the lower column of the familiar double column. There are, however, several important modifications to this cycle which make possible the economical operation of the system.

First, about 12% of the volume of the air fed to the plant is withdrawn as nitrogen from the condenser; but instead of being used as reflux, as in the last flowsheet described, it is used for abstraction of heat, i.e. for cold production. The nitrogen, at saturation temperature and 5 atm., is passed through a heat exchanger in countercurrent with an auxiliary stream of high pressure air. Having given up a part of its cold content is liquefying this high pressure air, it is then expanded through a turbine, so that its temperature is lowered nearly to saturation. The turbine exhaust is then passed through a further heat exchanger in countercurrent with the same stream of high pressure air, and finally leaves the plant at the ordinary temperature. The auxiliary stream of air is compressed to about 250 atm. and in some cases pre-cooled with liquid ammonia in a refrigeration circuit, as is shown in Fig. 4, before undergoing heat exchange with the nitrogen (the final air-nitrogen heat exchanger is not shown). By this process the high pressure air is partially liquefied, and it is then expanded into the main double column, where its cold content can be used to make up cold losses.

The second way in which the double column shown differs from those so far discussed is in the use of subcooling. The liquid nitrogen withdrawn from the lower column for use as reflux leaves at a temperature of 92°K by reason of its pressure. On expansion to atmospheric pressure it reaches a temperature of 78°K, and there is of course a considerable flash loss. By countercurrent heat exchange with the cold nitrogen product leaving the column, it is possible to sub-cool the liquid nitrogen before expansion and thus to save most of the flash loss. The resultant improvement in the reflux ratio increases the performance of the column, and is indeed necessary if such a large proportion of nitrogen is to be withdrawn for turbine expansion.

Saving in Power Consumption

Another type of Linde-Frankl plant uses an expansion engine cold production circuit of the type discussed in the first article of this series on the high pressure air circuit ("British Chemical Engineering," June, 1956, pp. 84-87). In this case no nitrogen is required for turbine expansion, and there would be an excess of reflux over the optimum; but this excess is absorbed by blowing into the upper column a quantity of air which has not been through the lower column, because it has only been compressed to 1.9 atm. The quantity of this low pressure air is approximately equal to that of the oxygen fraction, and it passes through that pair of regenerators which are cooled with oxygen. The low pressure to which this gas is compressed makes possible a saving in power consumption, though the final performance is only marginally better than that of the Linde-Frankl plant already described.

World War II stimulated research and development work in many fields, and one of these was the industrial separation of air. Although the main objective of the wartime research was the development of portable oxygen plants to supply Army workshops in the field, one new medium purity oxygen circuit emerged as a by-product. This was due to the Kellogg Corporation. It is illustrated in Fig. 5.

Air is compressed to 6 atm. and passed through a catalytic oxidation process in order to remove traces of hydrocarbon gases, particularly acetylene, which have on occasions caused explosions in oxygen plants. The compressed air is then cooled in the after-cooler of the compressor before entering the reversing exchangers which are the most novel features of the plant. In this exchanger it deposits its water and carbon dioxide, and is cooled to

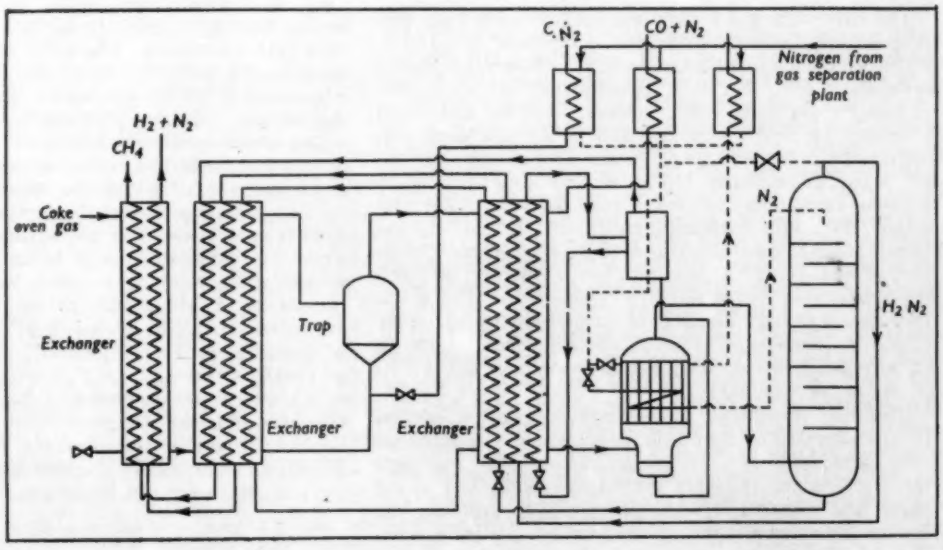


Fig. 6. Flowsheet of Linde-Bronn process for manufacture of synthesis gas from coke-oven gas.

105°K. It then passes through a set of filters which remove residual entrained impurities.

At the outlet of the filters the air is divided into three streams. The first of these is returned through the heat exchanger to provide the balancing flow without which the impurities deposited could not be completely revaporised; this subject was discussed in my second article. ("British Chemical Engnieering," July, 1956, pp. 138-141.) The air thus re-warmed leaves the exchanger at 190°K, and is then re-cooled by a part of the waste gas; it is then mixed with the second portion of the air leaving the reversing exchanger. The mixture has a temperature of 120°K and is expanded through a turbine directly into the column.

The third and major portion of the cold compressed air enters the lower column, which is of conventional design, except that it has two sub-coolers. Filters are provided for the liquid fraction enriched in oxygen, in order to ensure the longest possible run for the unit. The nitrogen product leaving the column is passed through these sub-coolers, and then through the heat exchanger which re-cools the balancing air stream; the combined effect of these three exchangers is to warm the nitrogen stream to the same temperature as the oxygen stream leaving the column. Both are then passed into the reversing exchanger, whence after warming to room temperature the separated products are passed to the point of use.

In the preceding discussion the various air separation circuits have been used as examples in order to explain and illustrate the various points of technique which have grown up with the years. In a modern plant it will usually be found that advantage has been taken of progress, and the relatively simple circuits illustrated will all contain the sub-coolers, filters, and auxiliary heat exchangers which have contributed so much to efficiency. To give such circuits in detail, however, would have complicated the description unduly, and they have therefore been omitted.

Low temperature techniques are by no means confined to the separation of air. Among other processes, more plants have been erected to operate the Linde-Bronn system than any other. This process, for the separation of coke oven gas, was first applied in 1924, and produces a mixture of nitrogen and hydrogen in the ratio 1:3 for ammonia synthesis. The popularity of the technique has increased markedly since the war. A typical circuit is illustrated in Fig. 6.

Purification of Coke Oven Gas

The coke oven gas is carefully purified from hydrogen sulphide and carbon dioxide and compressed to 13 atm. It then enters the first heat exchanger, in which it is cooled to about 175°K. No bulk condensation occurs in this exchanger; although water, residual benzole, and small quantities of liquid propylene and ethane are deposited, the quantities are very small. In the second exchanger the gas is further cooled to 130°K, and a considerable liquid fraction, containing the greater part of the ethylene and ethane, and a little methane, is condensed out. This fraction is collected in vessel T. The cold coke oven gas is then further cooled to 95°K in a third heat exchanger, in which the greater part of the methane is condensed. The gas is then passed through the tubes of a dephlegmator which are cooled by immersion in liquid nitrogen. This cooling to 82°K removes the residual methane, together with a part of the carbon monoxide.

The final purification of the coke oven gas is effected in a fractionating column, in which the gas is scrubbed with liquid nitrogen in countercurrent. This treatment removes the last traces of carbon monoxide, and at the same time replaces it with nitrogen. The synthesis gas leaving the column is more free from the catalyst poisons, oxygen and carbon monoxide, than the gas obtained by using chemical methods of purification. As it leaves the column, however, its nitrogen content is but 15%, and it is necessary to add further nitrogen in order to make the gas suitable for synthesis. This is done by adding cooled high pressure nitrogen at this stage, the cold content of the compressed nitrogen, thus expanded to a partial pressure of 4 atm., adding a major part of the refrigeration requirements of the unit. The cold synthesis gas is not expanded from the pressure of 13 atm. at which it entered the plant, but passes through the heat exchangers which are necessary in order to restore it to atmospheric temperature with only a small frictional loss in pressure. The condensed liquid products, however, are all expanded to atmospheric temperature, in order that by their lower boiling points they can effectively transfer their latent heat to the incoming gas.

The refrigeration requirement of the unit is largely met by the Joule-Thomson expansion of nitrogen, which is compressed to 250 atm. for this purpose. Rather more nitrogen is compressed than is needed for admixture with the hydrogen, the remainder being expanded at low temperature within the unit and recirculated. This nitrogen has of course to be manufactured in a special air separation plant.

Finally, one gas-separation process which has been much discussed in recent years concerns the separation of deuterium (heavy hydrogen) by the distillation of liquid hydrogen; the deuterium would be burnt in oxygen to give heavy water, which is in demand for use in nuclear reactors. Most processes for the production of heavy water involve heavy plant costs and absorb large amounts of energy. The advantage of the low temperature separation lies in the fact that by distillation, hydrogen and deuterium are no more difficult to separate than oxygen and argon. The technical problems involved in the maintenance of such very low temperatures, and in the purification of the hydrogen feed from the unavoidable traces of nitrogen, which would otherwise solidify and block the plant, are immense, and no one is yet known to have solved them on a commercial scale.

However, given a hydrogen feed stream of sufficient purity, for example, such as could be obtained if the hydrogen were generated electrolytically, the process could be carried into effect in the following manner. The hydrogen feed is compressed to 8 atm., and is cooled by heat exchange with the deuterium-free product to 45°K, and then further cooled until it is mostly liquefied in a second heat exchanger. It is then expanded through a valve into the column, where the heavy hydrogen is concentrated by stripping. Both feed and reflux liquid are evaporated in the column sump, and the vapours pass up the column, becoming progressively poorer in deuterium.

The deuterium-free hydrogen leaving the column, comprising both feed and reflux, is passed through the heat exchanger which liquefies the incoming feed stream, and the deuterium-free stream then splits into two parts. One-third is used to cool the feed stream as already described, while the remainder is used to cool the incoming reflux stream. After warming to room temperature, it is compressed to 8 atm., and passed into the reflux heat exchanger. Here it is cooled to 45°K, and then expanded in a turbine to 2 atm. absolute. The turbine exhaust is practically saturated at this pressure, and is then liquefied in the evaporator-condenser at the base of the column, thus providing the necessary boil-up. The deuterium-free liquid hydrogen is then expanded through a valve to act as reflux and so rectify the feed hydrogen so that a high yield of deuterium can be obtained.

(Fig. 5 is based on a diagram in W. E. Lobo's article in *Chemical Engineering Progress*, 1947, **1**, 21.)

Explosion Detection and Protection

RESEARCH work carried out during the war into explosions in aircraft fuel tanks has been developed into a system to protect industrial plant against the hazards of explosions. The system, developed and marketed by the Graviner Manufacturing Company, has been used to protect plants producing such products as wood flour, icing sugar and finely divided sulphur. It can also be applied wherever there is a fire hazard due to dust, fine powders, gases and vapours. The original research work showed that there is a definite time between ignition of an explosive mixture and the development of the maximum pressure. Initial rates of pressure rise are much less than those in the later stages and in many cases the pressure reached is proportional to the cube of the time after ignition. If the explosion can be detected and suppressed early enough the pressure rise need not be more than 1-3 psi.

Graviner engineers have developed a detector which is operated by a pressure rise of the order of 5 psi/sec, which corresponds to an absolute pressure rise of only 0.1-0.5 psi. Through an electrical circuit the detector is made to operate a suppression system, bursting disc or isolators. This detector is the trigger for all Graviner explosion protection devices. Generally speaking, any explosive mixture which, when ignited in a confined space, produces maximum pressure in not less than 40 milliseconds can be brought under control by these techniques. The system is applied as one or more of five principal methods—suppression, venting, isolation, advance inerting and automatic plant shutdown and are given briefly below.

Suppression: A single suppression system, shown diagrammatically in Fig. 1, consists of the explosion detector which, through an electrical power unit, causes a blanket of finely divided suppressing liquid to be dispersed from a hemispherical suppressor. The dispersal of the suppressant is much faster than the travel of the explosion front, typical figures showing detection in five milliseconds and complete distribution of the liquid in 10-20 milliseconds.

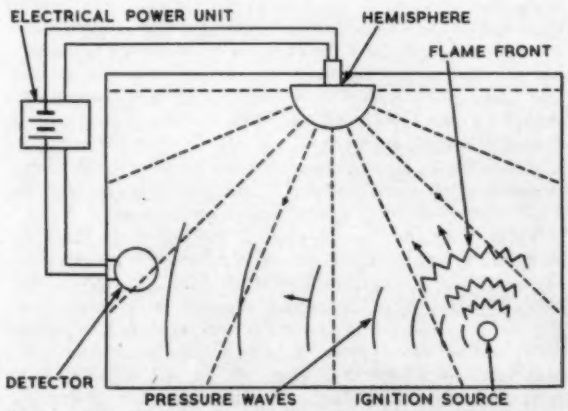


Fig. 1. Showing the operational cycle of the pneumatic type detector.

Fig. 2. Cutaway view of a hemispherical suppressor.

A single hemispherical suppressor is shown in Fig. 2. It consists of a hemisphere filled with suppressing liquid such as carbon tetrachloride or methyl bromide and fitted with an electrically fired detonator in the base. When the detector closes the circuit the detonator shatters the hemisphere and distributes the suppressant at a speed of 200 ft/sec. A typical figure for the speed of propagation of the explosion front is only 10 ft/sec.

In the system shown in Fig. 1 a pneumatic type detector is set to operate at a given pressure and at a given rate of pressure increase, greater than that likely to occur during normal processing. By using the two criteria the earliest possible detection of either slow or fast explosions is ensured. An electrical power unit receives the signal from the detector and passes it on to the suppressor. The power unit is fitted with a number of safeguards, including protection against power failure and damage to the circuits.

Venting: Under conventional plant protection venting is caused by the explosion pressure itself bursting a weak point in the plant such as a bursting disc. Such discs are often ruptured by corrosion or fatigued by constant changes of pressure as processing is carried out. In addition they have to be impractically thin to "blow" at very small pressure increases. Graviner have developed a bursting disc which overcomes all these faults. Their "Armourplate" glass bursting disc consists of a sheet of tough glass much stronger than is needed to resist the pressure in the plant. When an explosion starts it is detected and a signal is relayed to a detonator in the bursting disc which literally blows up the diaphragm. Such discs can be set to relieve the system at very low pressures.

Advance Inerting: An explosion starting in one part of a plant can travel through the system and cause extensive damage in vessels well away from the seat of the explosion. This danger is often overcome by dispersing a suppressant into vessels that could possibly be affected.

Isolation: An alternative to advance inerting to prevent the propagation of the explosion front is to seal off sections of the plant by means of a high-speed isolation valve. An 8 in. valve of this type can be closed in approximately 80 milliseconds and can withstand a pressure of 150 psig.

Automatic Shutdown: In addition to operating the protection devices, the electrical power unit supplied by Graviners is fitted with extra circuits which can be fitted to cause complete plant shutdown.

More stringent legislation to reduce atmospheric pollution caused by industry is in prospect. It therefore becomes more important to secure maximum dispersal of airborne effluents by erecting stacks of the right height

DISPERSAL OF AIRBORNE EFFLUENTS FROM STACKS

by SIR GRAHAM SUTTON, C.B.E., D.Sc., F.R.S.*

ONE of the major advances towards more civilised living that has been achieved in this century is that we in Britain have at last recognised that pollution of the amtosphere is a grave evil, but fortunately one that is remediable. In this country, industrial and domestic sources of pollution are about equally balanced. Domestic smoke is the more difficult to deal with, because of the love of the Englishman for a blazing hearth, our old-fashioned grates and the fact that supplies of smokeless fuel are limited. Industrial sources on the other hand are more amenable. In the manufacture of chemicals or the production of electrical energy, to quote only two examples, it is impossible to avoid the production of large quantities of unwanted gases or particulate matter. The problem is to get rid of these by-products in the least harmful manner.

The method which has been common since the dawn of the industrial era is to build a tall stack and to let the gases or smoke disperse freely into the air. Usually the effluent is hot and natural convection is sufficient to ensure that the gases and grit reach the top of the stack, there to be blown away by the wind.

This process is so ancient and universal that it comes as something of a shock to find that relatively little was known about the physics of the process until recently. The dynamics of a plume of hot gas ascending in a cooler atmosphere was not properly investigated until 1941, and then only for the somewhat artificial case of a completely calm atmosphere. The older textbooks of heat devoted at the most a few pages to natural convection (usually as an illustration of the "method of dimensions") and there were extant a few empirical formulæ derived by engineers for particular cases. But fundamental questions, such as those relating to the fall of temperature with height in the column, or the effects of wind on the plume, were unanswered until recently, and even now the problems are far from being completely solved. Yet clearly the designer of industrial plant must have such basic information if he is to grapple with the problem of dispersal of effluent in a scientific fashion.

The main facts concerning the diffusion of smoke or gas in the atmosphere are known qualitatively and, to a certain extent, quantitatively. A state of complete calm is rare in the atmosphere; usually, a wind blows and the motion is turbulent. As a result, diffusion is much more rapid than in laminar motion and, unfortunately, more complicated. The diffusing power of the lower atmosphere cannot be expressed by a single constant coefficient of diffusivity. However, if the wind is sufficiently strong, methods are known whereby the concentration of foreign matter at ground-level downwind of a source of known strength can be calculated with an accuracy adequate for most problems of atmospheric pollution.[1] The limiting factor is often not meteorological uncertainties but lack of data on the physiological effects of pollutants.

There are, however, some purely physical limitations to the applicability of these formulæ. In the first place, existing theories apply only when the gases emitted are so diluted with air that they differ inappreciably in density from the ambient atmosphere. This means, in practice, that very hot sources cannot be included. Secondly, the mathematical expressions will give misleading results if they are used without modification, in conditions in which the turbulence of the atmosphere is made to depart by natural causes from its "normal" level. This applies with particular force to the case of a clear night, when the cooling of the ground by radiation sets up an inversion of the normal fall of temperature with height. Such an inversion not only reduces the wind in the surface layers but also damps out the turbulence, the overall result being that diffusion is greatly reduced. When the lower atmosphere is stratified in this way, existing theories of diffusion hardly apply, but it is always possible to make some estimate of the concentration levels provided that adequate micrometeorological data are available for the locality in question. Unfortunately, this is rarely so.

These formulæ, originally developed for chemical warfare, have been shown to be reliable—for the majority of atmospheric conditions—for distances up to a few miles downwind of a source situated at ground level. Fig. 1 shows the fall in concentration, measured at ground level, in the cloud from a point-source of matter in a moderate wind. For the purposes of the calculation it is assumed that the pollutant is either gaseous, or particulate to the extent that gravitational settling may be ignored and further, that there is no absorption of the cloud by

* Director, Meteorological Office, Air Ministry.

the ground. The decrease of concentration with distance is not quite as rapid as it would be if an inverse square law applied.

In the work described above, the source is supposed to be placed at ground level. When the source is elevated, as with a stack, the distribution of concentration downwind is entirely different. Fig. 2 shows, qualitatively, the effect of elevating the source. At the foot of the stack the concentration is theoretically zero and initially the cloud diffuses as if the ground were absent. At some distance downwind, however, the cloud is of sufficient vertical extent to touch the surface of the ground, which acts as an impermeable barrier. The result is that the concentration measured at ground level rises fairly rapidly to a well-defined maximum at a relatively short distance downwind of the stack and then decreases slowly to zero.

Formulae for Concentrations from a Steady Source

The cloud from a point-source spreads out in the form of a cone. At any instant, the dimensions of the cone are determined by the smaller eddies in the wind, but over an appreciable period of time, say 5 minutes or more, the cone swings over a fairly wide arc. This swinging of the cone is equivalent to an additional diffusion, and in consequence it is necessary to consider average concentrations over a specified period. Nearly all the existing data refer to such "time-mean concentrations" where the period of averaging is of the order of *minutes*, at least.

The central, or peak, concentration χ of matter at a distance x downwind of a ground-level source emitting matter (gaseous or particulate) at a rate Q, in a wind of speed u, is given by an expression of the form

$$\chi = \frac{Q}{\pi C^2 u x^{2-n}} \quad \ldots\ (1)$$

where C is a generalised diffusion coefficient and n is a parameter depending on the degree of turbulence in the atmosphere. In "average" conditions, when the vertical gradient of temperature near the ground is small, the value of n is about $\frac{1}{4}$, but in inversions n increases towards an upper limit of 1. The value of C also depends upon the turbulence of the wind.[1]

For elevated sources, such as stacks, the expressions are naturally more complicated. It will suffice here to quote two results only, relating to the *magnitude* and *distance downwind* from the foot of the stack of the maximum concentration at ground level. These are, in the simplest cases,

$$\chi_{max} = \frac{2Q}{e\pi u h^2} \quad \ldots\ (2)$$

$$x_{max} = \left(\frac{h^2}{C^2}\right)^{1/(2-n)} \quad \ldots\ (3)$$

where h is the height of the stack orifice and e is the base of natural logarithms.

These expressions were derived by the writer in 1947.[2] They bring out the interesting result that the maximum concentration of the effluent found at ground level varies inversely as the square of the height of the stack orifice above ground. This law was discovered by C. H. B. Bosanquet and J. L. Pearson in 1936.[3] The formulæ were examined by C. A. Gosline[4] in 1952, who found good agreement with observations made on the dispersal of effluent from a chemical works.

Effect of a Hot Source

The above expressions refer to a source which is effectively at the temperature of the ambient air. When the gases are hot, the behaviour of the cloud is much more complicated (see Fig. 3). The beneficial effects of adding heat to an effluent were first demonstrated by Hill, Thomas and Abersold,[5] who investigated conditions in the neighbourhood of a stack emitting gases containing sulphur dioxide, at Murray, Utah. At first, Murray had a 200-foot stack, then one of 300 feet and finally a 450-foot stack was built. An attempt was made to reduce ground concentrations of SO_2 in the vicinity of the plant by the initial dilution of gases by blowing in air at the base of the stack. The result was that the gases were cooled, and at $\frac{1}{4}$ to $\frac{1}{2}$ mile away the concentrations were higher when the fan was operating than when it was not. Finally, a coal-burning stack heater was placed at the base of the stack, with the result that concentrations of SO_2 were reduced to a low level at all distances downwind (see Fig. 4).

This example is important because it demonstrates that not only that high stacks and high effluent temperatures are effective means of reducing ground concentrations, but also that any influence which tends to reduce the temperature of stack gases is bound to have adverse effects on concentrations at breathing level. A hot source is equivalent in its effect to an increase in the height of the orifice, and since the maximum concentration at ground level is inversely proportional to the square of the height of the orifice above ground, the benefit is likely to be significant. On the other hand, these facts throw some doubt on the efficacy of gas-washing as a means of

Fig. 1. Ground level concentrations from a cool source (at ground level) emitting 1 kilogram/sec in a wind of 5 metres/sec; small vertical temperature gradient.

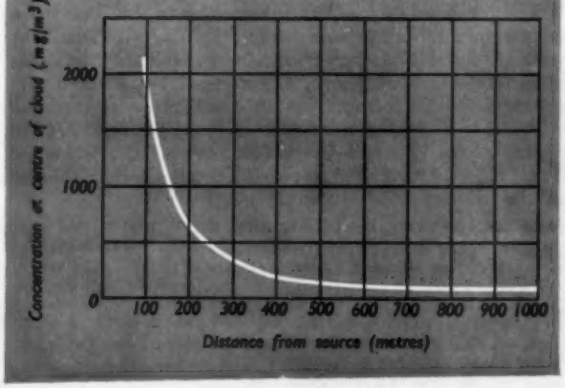
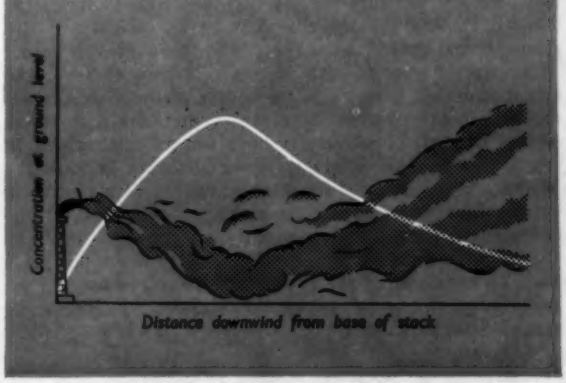


Fig. 2. Concentration from an elevated source (theoretical).



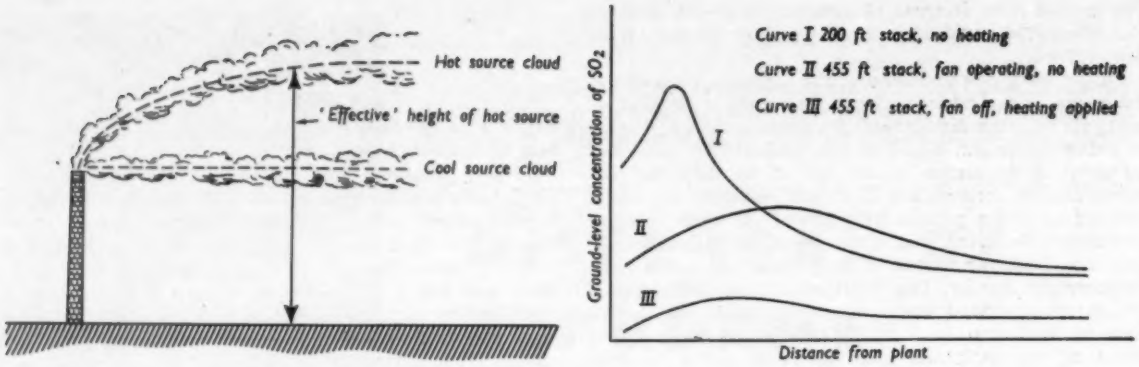

Hot source cloud
'Effective' height of hot source
Cool source cloud
Curve I 200 ft stack, no heating
Curve II 455 ft stack, fan operating, no heating
Curve III 455 ft stack, fan off, heating applied
Ground-level concentration of SO_2
I
II
III
Distance from plant

Fig. 3 (left). The effect of convection on the apparent height of a source of pollution. Fig. 4 (right). Effect of increase of stack height and heating on pollution (based on Hill, Thomas and Abersold's measurements at Murray, Utah).

reducing SO_2 pollution. Gas-washing is bound to lower the temperature of the effluent, and unless it is very efficiently carried out the net result may be an increase in the pollution in the vicinity of the source. The balance between the decrease in pollution by partial removal of the sulphur oxides and the increase in pollution by cooling of the effluent from, say, coal- or oil-burning power stations, is delicate, and it is for this reason, as much as any other, that attention is now being given to means of estimating as accurately as possible the path followed by a heated plume in the presence of wind.

The Dynamics of Natural Convection

From these considerations, it is evident that the engineer concerned with the reduction of pollution needs to know the gain in "effective" height achieved by conserving heat in the effluent, or even by adding heat. It is here that the real difficulties of the problem arise. A plume of hot gas is very easily bent over by a horizontal wind, but in these conditions the dispersion is partly caused by dynamic turbulence and partly by the eddying motion arising from buoyancy. A complete solution is not to be expected at the present stage of development of fluid mechanics, and the mathematician must fall back on approximate methods.

Although the problem of the plume in *calm* air is of little practical importance, it is as well to give here the main lines of the simple solutions that can be derived in this instance. If molecular processes (viscosity, conduction of heat) are neglected in comparison with the turbulent mixing processes, dimensional analysis shows that the temperature excess in the plume varies as $(\text{height})^{-5/3}$ and the upward velocity as $(\text{height})^{-1/3}$, the plume being conical in shape. Laboratory measurements with small plumes indicate departures from these simple relations and in these cases the radius of the plume cross-section increases rather more slowly than the first power of the height.[6] These results hold for an atmosphere in which the vertical gradient of temperature outside the plume is small. For a stratified atmosphere (e.g., one in which there is a marked inversion of temperature) the corresponding results are naturally more complicated and the reader is referred to a recent paper by Morton, Taylor and Turner.[7] This paper contains among other things, some interesting estimates of the height to which a plume would rise in a calm I.C.A.N. atmosphere,* and it is calculated that with a large power station, in which heat equivalent to ½ megakilowatts is wasted, the smoke will rise to about 1200 metres. In contrast, a household chimney, with a fire burning 4 lb of coal an hour, half of which is wasted up the chimney (heat source equivalent to 8 kilowatts) would send smoke up to 80 metres). A further important point is that the temperature excess at any level is not directly proportional to the strength of the source, but, in the case of a non-stratified atmosphere, to $(\text{source})^{2/3}$.

A cognate problem, but one which is unlikely to trouble the industrial engineer, is that of the rise of the cloud of debris and hot gases from an explosion, e.g., of an atomic bomb. A recent American official publication[8] gives a formula derived by the writer for the maximum height reached by the cloud; it is interesting that in this case the height varies aproximately as $(\text{source})^{\frac{1}{4}}$ so that the level at which the cloud comes to rest does not depend markedly on variations in the heat developed by the explosion.

The Bent-Over Plume

The problem of the hot plume in a horizontal wind is, as stated above, considerably more difficult to analyse and the working engineer may well be bewildered by the abundance of expressions that have been developed so far to predict the behaviour of such clouds. In 1950, Bosanquet, Carey and Halton[9] developed elaborate expressions for the rise of a heated plume in a wind, bringing in not only the effect of heat but also that of the forced draught in the chimney. In the same year the writer produced an approximate solution for the shape of the plume in a wind when the rise is caused by natural convection only.[10] In 1953, Holland[11] analysed observations at Oak Ridge, Tennessee and deduced a very simple empirical formula for the rise. This work, together with other formulæ, is quoted in the publication of the U.S. Atomic Energy Commission referred to above.[8] Finally, in 1956, Priestley published yet another solution of the problem.[12]

In the following list of formulæ, the symbols used are:

u = mean wind speed (ft sec.$^{-1}$)
v_o = forced draught in stack (ft sec.$^{-1}$)
T_o = effluent temperature; T_1 = ambient air temperature (°C)
$\triangle = T_0 - T_1$
Q = rate of emission of effluent (ft^3 sec.$^{-1}$)
g = acceleration due to gravity
d = stack orifice diameter (ft).

* This is a standard atmosphere for which I.C.A.N. (International Commission for Air Navigation) proposed the specification.

Bosanquet-Carey-Halton expressions

Maximum rise caused by forced draught $= \dfrac{4{\cdot}77}{1 + 0{\cdot}43\ u/v_s} \dfrac{\sqrt{Qv_s}}{u}$

maximum rise caused by buoyancy $= 6{\cdot}37g \dfrac{Q\triangle}{u^3 T_1} Z$

where Z is a function given graphically, or by a somewhat complicated formula.[8]

Sutton formula

The path of the plume is given in terms of distance along the central line of the plume (s), the height above the orifice (z) and the inclination of the plume to the horizontal (ψ)

$$s = \left(\frac{v_1}{u}\right)^3 \cot^3 \psi$$

$$z = \frac{3}{2}\left(\frac{v_1}{u}\right)^3 [\cot \psi \operatorname{cosec} \psi - \log_e (\cot \psi + \operatorname{cosec} \psi)]$$

where v_1 is a parameter occurring in the expression for the convective velocity in a plume in calm air (and thus calculable in terms of the heat output).

Bryant-Davidson formula

$$\text{rise of plume} = d\left(\frac{v_s}{u}\right)^{1.4}\left(1 + \frac{\triangle}{T_s}\right)$$

(T_s = stack temperature on absolute scale)

Holland ("Oak Ridge") formula

$$\text{rise in feet} = \frac{1{\cdot}5v_s d + 3 \times 10^{-4} Q_H}{u}$$

(Here u and v_s are in miles per hour, d in feet and Q_H, the heat source, in calories per second.)

A modified form of the original Bosanquet-Carey-Halton formula has been used by Hawkins and Nonhebel[13] in a recent paper, but since this involves functions shown graphically, no formula can be quoted here. Priestley's analysis is also unsuitable for quotation as a formula.

The engineer confronted with such expressions of such widely different appearance may well despair of reaching any conclusion, especially as the same parameters do not appear in all the formulæ. Fortunately, some comparisons are available. Priestley, in the paper cited, gives a comparison of the calculated and observed heights for the Bosanquet-Carey-Halton, Sutton and Priestley theories. This shows that the expressions derived by Bosanquet *et al* give an underestimation of about 17%, the Sutton expression overestimates by about 38%, and the Priestley method gives heights which are, on the average, very close to the observations. The problem has also been considered by Best[14] who carries the computations to the final point, that of estimating the effects of forced draught and heating of the gases on the maximum pollution concentration at ground level, using the expressions of Bosanquet *et al*, Sutton and Holland. Despite the fact that there are often considerable differences in the height estimations, the values for the concentrations are in reasonable agreement, reasonable, that is, when the variability and uncertainty of the meteorological and physiological data are taken into account. (Even for SO_2, the most common atmospheric pollutant, the range of concentrations regarded as "tolerable" by the average human being for indefinite exposure, is very large.)

Practical Conclusions

There can be no doubt that in designing stacks for the dispersal of gaseous or particulate pollution, the golden rule is: *make the stack as high as possible and conserve heat.* It has been shown by the writer[1] that the reduction of concentration at ground level is proportional to the added heat, and inversely proportional to the height of the stack and the cube of the wind speed. In other words, in high winds, there is little advantage to be gained by adding heat, but in these circumstances the high wind reduces concentrations to an acceptable low level by straightforward dilution. The main difficulty in dealing with pollution arises when the wind is low.

The various expressions that have been derived for the height attained by the heated plume do not agree too well among themselves, but as Best has shown, this is not too serious in practice because the effect of the variations on the ground concentration is within the margin of uncertainty of the meteorological and physiological factors.

The engineer faced with the practical problem of deciding upon stack heights, effluent temperature, etc., to bring pollution to an acceptable low level in the neighbourhood of the plant could probably do no better at present than to rely upon the "Oak Ridge" formula as given in the Report of the Beaver Committee[15] on atmospheric pollution. This is

$$\text{Maximum concentration at ground level} = \frac{9 \times 10^6 Q}{h(14vd + Q_H)}$$

where Q is the strength of the source in lb. sec.$^{-1}$
h is the height of the orifice above ground in ft
v is the velocity of efflux in ft sec.$^{-1}$
d is the stack orifice diameter in ft
Q_H is the rate of heat output in Btu sec.$^{-1}$

Much useful information concerning the behaviour of plumes from stacks, and about the dispersion of pollution in general, is to be found in *Meteorology and Atomic Energy*.[8] The fuel expert should also consult the paper by Hawkins and Nonhebel.[13]

Appendix

The following notes on the methods employed in the derivation of the various formulæ may be useful to those interested in the more theoretical aspects of the problem of the bent-over plume.

The formulæ of Bosanquet *et al* was derived by considering the motion of the plume relative to the ambient air and by combining the dilution arising from this cause with that produced by turbulence. The derivation is long and complicated and has not been published *in extenso*.

Sutton's formula is based upon the solution of a cognate problem in particle dynamics, that of finding the trajectory of a particle subjected to a constant horizontal velocity (the wind) and simultaneously to an upward velocity which decreases with distance along the trajectory according to the law established for the convective current in a free jet ascending in a calm atmosphere.

The Bryant-Davidson formula is an empirical reduction of wind-tunnel observations. The Oak Ridge (Holland) formula is an empirical reduction of observations made on plumes from stacks. Priestley's theory is hydrodynamical.

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THE INTER-DISPERSION OF IMMISCIBLE FLUID PHASES

by P. H. CALDERBANK, Ph.D., A.M.I.Chem.E.

THE dispersion of one phase in another phase with which the first is immiscible is important in many chemical engineering operations. Dispersion is a means of bringing about a large increase in the interfacial area available for material or heat transfer, while at the same time both fluids are brought from a stagnant condition into a state of motion which serves to increase the specific rates of both of the above transfer processes.

In the design of two-phase contacting plant, operating conditions are first chosen to secure favourable driving forces and batch, cocurrent or countercurrent equipment is decided upon, as is also the relative flow rates of the two phases.

Having evaluated the minimum number of transfer units required for the proposed duty, from the above considerations of maximum driving force, attention must be directed to the dispersion process itself, the efficiency of which determines the height of a transfer unit. The latter which should be minimal, depends in inverse manner on the magnitudes of the transfer coefficient and interfacial area and directly on the flow velocity. Thus if the flow velocity and output are to be maximal, the transfer coefficient and interfacial area must be as large as possible.

If the process is chemical-reaction-rate controlled the above principles still apply, with the proviso that the transfer coefficient is renamed the reaction velocity constant and becomes strongly temperature-dependent.

In the general case, efficiency in dispersion must be accompanied by a corresponding efficiency in phase separation since the effects of entrainment are deleterious.

Attention will here be directed to the dispersion process itself. Of the several ways in which dispersion may be brought about the most important are: the introduction of one phase through jets or orifices into the other phase, which may itself be either stationary or flowing; and the mechanical agitation together of the two phases.

Mechanical agitation is resorted to when very high rates of transfer, unattainable by other means, are demanded. Even when the process requires many stacked equilibrium stages and where mechanical problems are severe, it has sometimes proved economic to employ mechanical agitation as in rotary and centrifugal extraction equipment, spinning band columns and the like.

In gas-liquid contacting, plate columns employ the principle of dispersion through orifices and the vapour flow rate is generally high enough to secure a thorough agitation of the liquid phase at the same time as a large interfacial area is presented. In fermentation processes, however, the gas flow rate is relatively low and the gas hold-up generally less than 5% as opposed to a normal figure of about 60 or 70% in plate columns. Consequently, in the former case, mechanical agitation is used to bring about better contacting. The principles involved may be seen by consideration of an assembly of equal spheres dispersed in a continuous phase.

Thus $a = 6H/D$

where a = interfacial area per unit volume of mixed phases
H = fractional volumetric hold-up of dispersed phase
D = equivalent spherical diameter of one drop or bubble of the dispersed phase.

The interfacial area may be increased by increasing the hold-up or by reducing the bubble or drop diameter. For a fine grained dispersion in which the bubbles or drops obey Stoke's law,

$$D \propto V^{\frac{1}{2}}$$

where V is the velocity of rise or fall of the sphere. Moreover $H \propto 1/V$ so that,

$$a \propto D^{-3/2}$$

These arguments, which favour the use of fine grained dispersions, have to be scrutinised in the light of the energy necessary to produce them. Also it is known that the fluid comprising small drops or bubbles is essentially static, while that comprising larger drops or bubbles is in a state of circulation which serves to increase the transfer coefficients within both phases. The latter may be still further increased if the drop or bubble is large enough to oscillate between oblate and prolate spheroidal forms.

In contacting most liquids with gases, the hold-up may be increased by increasing the gas flow rate until the foam density reaches a value of about $0.35\rho_L$ where ρ_L is the liquid density. Little further increase in hold-up can be realised in practice, this critical condition corresponding fairly closely with what would be expected from the closest packing of equal spheres. However, in some cases of liquids of low surface tension (e.g., detergent solutions, fire-fighting foam, ore flotation-fluids, etc.), extremely low foam densities may be realised. It is clear in these cases that the dispersed phase no longer exists as spheres but as stacked straight-sided bodies, probably rhombic dodecahedrons.[1] It has been suggested that such low-density foams have advantages in high-efficiency one-stage gas absorption equipment.[2]

All the evidence available goes to show that variation of the orifice diameter, of itself, does not solely determine the bubble size in gas-liquid contacting. The stable bubble size also depends on the level of turbulence existing in the continuous phase, and this level will, of course, be higher as the orifice diameter is decreased with consequent increase in energy dissipation, observed as pressure drop. With increasing

*Chemical Research Laboratory.

viscosity of the continuous phase, increasing amounts of energy are absorbed by viscous dissipation and smaller amounts appear as turbulent fluctuations. Under these conditions, small bubbles which may be initially formed from fine orifices eventually coalesce into larger ones, the ultimate size being determined by the turbulence level. The point which is emphasised is that the bubble size is not solely determined by conditions obtaining at its birth but also by the hydrodynamic field in which it subsequently finds itself.

In conventional plate columns, the fraction of the plate area occupied by holes or slots and the size of aperture is found by experience and is presumably a practical balance to secure a high level of turbulence in the continuous phase with an economic energy loss and a reasonably low entrainment. In practice it has been found satisfactory to design on the basis of a figure for maximum allowable entrainment.

In fermentation equipment, mechanical agitation is used to create a turbulent field in which only small bubbles may survive. Here it would be expected that the type of gas sparger used would be unimportant and this seems from practical experience to be the case.

Liquid-liquid extraction columns employing orifice dispersers are operated at close to flooding to obtain a maximum practical value of the hold-up. Such equipment may be filled with baffles or packing or agitated or pulsed to create increased turbulence in the continuous phase. For packed towers Pratt [3] has shown that a stable drop size is rapidly reached as the dispersed phase passes into the packing, this size being quite independent of that obtaining at the injection nozzles. This observation is in accord with the principle that the hydrodynamic field determines the stable drop or bubble size.

For rigorous design of contacting equipment, the foregoing qualitative observations, although a useful guide will not by themselves suffice. Although far from complete, recent work has gone some way in putting these matters on a quantitative basis.

A proper approach to these problems will have to take account of the following fundamental quantities.

1. *Bubble size or drop size*: This may be solely determined by conditions obtaining at the orifice disperser itself, in the particular case where drops or bubbles unlikely to contact each other, because of a low dispersed phase hold-up, enter a hydrodynamic field where the turbulence is low. In the general case the ultimate bubble or drop size will be determined by the level of turbulence in the continuous phase as caused by the injection of the dispersed phase alone or by the additional energy dissipated by mechanical agitation. At high jet velocities, the stream of fluid issuing from the jet may itself become turbulent. At and beyond this point atomisation of the phase to be dispersed will occur and give rise to initially fine grained dispersions.

2. *Terminal velocity of dispersed phase in fall or rise in continuous phase:* The fall or rise may be free or hindered if a packed contactor is used and the velocity is usually correlated with the bubble or drop size as a drag coefficient. The terminal velocity allows the hold-up to be evaluated, since

$$H = V_s/V_t$$

where V_s = superficial velocity

V_t = actual terminal velocity

H = fractional volumetric hold-up.

3. *Mass transfer coefficients in dispersed and continuous phases:* Internal circulation and bulk oscillation are both factors which will largely affect these quantities. In addition, interfacial effects accompanying mass transfer require evaluation.

Coefficients obtaining in agitated systems require separate evaluation from those found for directional flow systems.

If complete information on the above factors were available, it would be theoretically possible to design using the operating and equilibrium relationships for the system of interest. Even if operating and equilibrium lines were linear, the solution would be extremely laborious as resistances to diffusion within spherical shapes and through the continuous phase film are additive. This summation is not straightforward and involves much labour. Ignoring this difficulty, we would still be left with the problem of estimating column "end-effects" caused by the usually enhanced rates of transfer at the dispersion and coalescing sections of the column. These difficulties arise in contemplating the possibilities of a generalised solution although in particular cases a simpler situation and one capable of analytical treatment may exist. At the present juncture, however, we must be largely content to identify and estimate the effect of the important parameters which determine contacting efficiency. From such knowledge, a simplification of these apparently complex problems may hopefully be anticipated.

The present state of our knowledge of the three factors detailed above are considered in the following paper, and some hitherto unpublished results reported.

The Mechanics of Dispersion

In the following section the forces causing and resisting dispersion will be considered. Both static and dynamic forces will play a part in determining the stable bubble or drop size.

Static forces: Surface tension forces acting inwards at the interface of the drop or bubble resist any distortion which may ultimately lead to break-up, by attempting to retain sphericity. These forces are proportional to σ/D per unit area where σ is the interfacial surface tension and D the drop or bubble diameter.

If the interface is electrically charged by the adsorption of surface active ions, an outward force of electrostriction will oppose the surface tension forces. (Surface tension lowering by colloidal electrolytes.) The force of electrostriction is proportional to Q^2/KD^4 where Q is the electrical charge on sphere and K the dielectric constant of continuous phase.

Since adsorbed ions stabilise the dispersion by creating a diffuse electrical field of oppositely charged ions around the individual drops, such stabilisers are avoided in most chemical engineering operations where speed of phase separation is important. Forces of electrostriction will consequently not be considered further.

Dynamic forces: Due to the combined effects of gravity, buoyancy, and fluid flow, viscous and/or inertia forces are impressed on the drop or bubble. This overall dynamic pressure force will be represented by τ.

If τ does not act equally at all points of the surface, distortion is brought about and this may ultimately lead to break-up.

Internal circulation of the drop or bubble fluid follows as a result of distortion produced by the surface shear. Viscous stresses within the drop or bubble due to this internal circulation are consequently set-up, the order of magnitude of these forces being proportional to

$$\frac{\mu_d}{D}\sqrt{\left(\frac{\tau}{\rho_d}\right)}$$

where μ and ρ represent viscosity and density and the suffix d refers to the dispersed phase.

Thus we see that the forces acting on the dispersed phase are:

Surface tension force $= \sigma/D$ ....(1)

Dynamic pressure force $= \tau$ ....(2)

Viscous force in dispersed phase $\propto \frac{\mu_d}{D}\sqrt{\left(\frac{\tau}{\rho_d}\right)}$ ....(3)

The dynamic pressure force which tends to break up the drop or bubble is resisted by both surface tension and viscous

forces. Of the two forces resisting dispersion one or the other may predominate but it is important to realise that the viscous force increases with the dynamic pressure while the surface force does not. This means, for example, that under conditions of mild agitation, dispersion may be controlled by dynamic and surface tension forces while for severe agitation conditions, dynamic and viscous forces may control the process.

The ratio between any two of the above forces is a dimensionless magnitude, yielding two independent dimensionless groups.

Thus, for example, the two groups,

$$(We)_d = \tau D/\sigma = \text{ratio of inertia to surface tension forces (Weber number)} \quad \ldots.(4)$$

$$(Re)_d = \frac{D}{\mu_d}\sqrt{(\tau\rho_d)} = \text{ratio of inertia to viscous forces (Reynolds number)} \quad \ldots.(5)$$

may be chosen. Alternatively the groups,

$$(We)_d = \tau D/\sigma \text{ (Weber number)}$$

$$\text{and } (N_{Vi})_d = \sqrt{We}/Re = \mu_d/\sqrt{(\rho_d \sigma D)} \quad \ldots.(6)$$

(Viscosity group, surface tension number or Z group.) may be preferred since in this way one dynamic group and one physical property parameter is obtained.

The dynamic pressure τ which appears in these dimensionless groups will depend on the flow conditions in the continuous phase. Our ignorance of the precise details of the flow conditions in most cases is avoided by the use of gross experimental data.

Thus for directional flow systems τ is obtained from an experimental drag coefficient and Reynolds number, both arbitrarily defined.

$$\text{Thus } \tau \propto Cd.\rho_c V^2 \quad \ldots.(7)$$

where Cd = drag coefficient = $f(Re)_c$

V = relative velocity between dispersed and continuous phases.

$$(Re)_c = \frac{DV\rho_c}{\mu_c} \quad \ldots.(8)$$

and where the suffix c refers to the continuous phase.

If a flow situation with a clearly defined relative velocity between phases (V) is involved, the Reynolds number previously defined (equation 5) becomes

$$(Re)_d \propto \frac{D}{\mu_d}\sqrt{(Cd.\rho_c V^2 \rho_d)}$$

$$\propto \left(\frac{DV\rho_c}{\mu_c}\right)\left(\frac{\mu_c}{\mu_d}\right)(Cd)^{\frac{1}{2}}\left(\frac{\rho_d}{\rho_c}\right)^{\frac{1}{2}}$$

$$\text{i.e. } (Re)_d \propto (Re)_c\left(\frac{\mu_c}{\mu_d}\right)(Cd)^{\frac{1}{2}}\left(\frac{\rho_d}{\rho_c}\right)^{\frac{1}{2}} \quad \ldots.(9)$$

If the surface tension is low and the dynamic pressure high, dispersion is governed by a balance between inertia and viscous forces. That is, a critical value of $(Re)_d$ defines the point at which a drop or bubble breaks up. This critical value will, of course, depend on the particular nature of the flow field since some flow arrangements might be expected to be more efficient than others for causing dispersion.

For a particular flow field in which surface tension forces are negligible we may write

$$(Re)_{d\,(crit)} = \text{constant}$$

$$\text{or } (Re)_{c\,(crit)}\left(\frac{\mu_c}{\mu_d}\right)(Cd)^{\frac{1}{2}}\left(\frac{\rho_d}{\rho_c}\right)^{\frac{1}{2}} = \text{constant} \quad \ldots.(10)$$

If the dispersed phase is in the form of spherical drops or bubbles,

$$Cd \propto \frac{\Delta\rho}{\rho_c}\frac{D}{V^2} \quad \ldots.(11)$$

where $\Delta\rho = \rho_c - \rho_d$.

Combining equations 10 and 11 we find

$$D \propto \left(\frac{\mu_d^2}{\rho_d}\frac{\rho_c}{\Delta\rho}\right)^{\frac{1}{3}} \quad \ldots.(12)$$

showing that the drop or bubble size depends only on viscosities and densities and is independent of the relative velocity between phases. If D_0 is the diameter of the nozzle through which the phase to be dispersed is introduced, we may transform equation 10 to yield,

$$\frac{D}{D_0} \propto (Re)_d^{-1}\,(Cd)^{-\frac{1}{2}}\left(\frac{\rho_d}{\rho_c}\right)^{\frac{1}{2}} \quad \ldots.(13)$$

where $(Re)_d$ is now defined as $(D_0 V\rho_d/\mu_d)$, the nozzle Reynolds number.

Equation 13 is a potentially useful form for correlating results obtained on dispersing one phase through a nozzle into another phase which is stationary or flowing in a pipe or column with relative velocity V. If, however, the phase to be dispersed is introduced through the nozzle at high velocity, the effect of acceleration drag on Cd cannot be ignored. Experimentally Richardson [4] finds for the jet dispersion of a number of liquid systems,

$$\frac{D}{D_0} = 39.8\,(Re)_d^{-1}\left(\frac{\mu_c}{\mu_d}\right)^{\frac{1}{3}}$$

The above development refers to the case where surface tension forces are negligible and where viscous forces alone resist dispersion. The other limiting case of interest is where viscous forces are negligible and where surface tension forces alone resist dispersion.

For this case, a critical value of the Weber number defines the point of break-up of a bubble or drop:

That is $(We)_d$ = constant

and applying similar transformations to those detailed above we find

$$(We)_d = (We)_c(Cd) = \text{constant} \quad \ldots.(14)$$

$$D \propto \left(\frac{\sigma}{\Delta\rho}\right)^{\frac{1}{3}} \quad \ldots.(15)$$

$$\frac{D}{D_0} \propto (We)_d^{-1}\,(Cd)^{-1}\left(\frac{\rho_d}{\rho_c}\right) \quad \ldots.(16)$$

where $(We)_c = D\rho_c V^2/\sigma$ and where $(We)_d$ is here defined as $(D_0\rho_d V^2/\sigma)$, the nozzle Weber number (relative velocity between phases at nozzle = V).

Equation 15 has been tested by Hu and Kintner [5] for the breakdown of drops of liquid falling through other liquids and air. A reasonably satisfactory correlation of the form

$$D = \left[1.452 \times 10^{-3}.\frac{\sigma}{\Delta\rho}\right]^{\frac{1}{3}} \text{ cm is obtained.}$$

Rushton and Roy [6] in experiments on the dispersion of oil through a nozzle into water flowing turbulently in a pipe also conclude that viscous forces may be ignored and that their experimental results, although few in number, may be correlated in terms of the Weber number.

The drop or bubble diameters referred to above are maximum values. In practice a range of sizes is obtained and a statistical mean value is frequently quoted in experimental work. From the standpoint of design, the maximum values referred to above are most relevant since they will lead to a conservative figure for the interfacial area.

Of frequent practical interest is the case where the phase to be dispersed is introduced into a turbulent field of the continuous phase, as, for example, when a mechanical agitator is used to disperse the contents of a tank. If it is assumed that the turbulence is homogeneous and isotropic and that turbulent fluctuations are alone responsible for the dispersion process, following Hinze [7] we may conclude that the dynamic pressure due to turbulence is given by

$$\tau = C_1\rho_c\left(\frac{PD}{v\rho_c}\right)^{\frac{1}{3}} \quad \ldots.(17)$$

where P = total power input

C_1 = a dimensionless constant and

v = total volume of fluid.

Thus from equation 5

$$(Re)_d \propto \frac{D}{\mu_d}\left[\rho_c\left(\frac{PD}{v\rho_c}\right)^{\frac{2}{3}}\rho_d\right]^{\frac{1}{2}} \quad \ldots.(18)$$

If we now confine our attention to a mechanically agitated tank disperser, equation 18 may be transformed into terms of the Reynolds and Power numbers normally used in this field of work. Thus:

$$(Re)_d \propto \left(\frac{D}{L}\right)^{\frac{2}{3}}\left(\frac{NL^2\rho_c}{\mu_c}\right)\left(\frac{\mu_c}{\mu_d}\right)\left(\frac{P}{\rho_c N^3L^5}\right)^{\frac{1}{2}}\left(\frac{L^3}{v}\right)^{\frac{1}{2}}\left(\frac{\rho_d}{\rho_c}\right)^{\frac{1}{2}}$$

$$\text{or} \quad (Re)_d \propto \left(\frac{D}{L}\right)^{\frac{2}{3}}(P_{No})^{\frac{1}{2}}\ (Re)_c\left(\frac{\mu_c}{\mu_d}\right)\left(\frac{L^3}{v}\right)^{\frac{1}{2}}\left(\frac{\rho_d}{\rho_c}\right)^{\frac{1}{2}} \quad \ldots.(19)$$

where L = agitator diameter,
N = agitator speed in, for example, revolutions per minute,
(P_{No}) = Power number = $P/\rho_c N^3L^5$,
$(Re)_c$ = Reynolds number = $NL^2\rho_c/\mu_c$ and
v = volume of tank contents.

If surface tension forces are negligible compared to viscous forces, a critical value of $(Re)_d$ determines the maximum drop or bubble size and we obtain the result

$$\frac{D}{L} \propto (P_{No})^{-\frac{1}{2}}\ (Re)_c^{-\frac{2}{3}}\left(\frac{\mu_c}{\mu_d}\right)^{-\frac{2}{3}}\left(\frac{L^3}{v}\right)^{-\frac{1}{2}}\left(\frac{\rho_d}{\rho_c}\right)^{-\frac{2}{3}} \quad \ldots.(20)$$

In similar fashion, from equation 4, we obtain

$$(We)_d \propto \left(\frac{\rho_c N^2L^3}{\sigma}\right)\left(\frac{D}{L}\right)^{\frac{2}{3}}\left(\frac{P}{\rho_c N^3L^5}\right)^{\frac{1}{2}}\left(\frac{L^3}{v}\right)^{\frac{1}{2}} \quad \ldots.(21)$$

$$\text{or} \quad (We)_d \propto (We)_c\ (P_{No})^{\frac{1}{2}}\left(\frac{D}{L}\right)^{\frac{2}{3}}\left(\frac{L^3}{v}\right)^{\frac{1}{2}}$$

and if viscous forces are negligible compared with those of surface tension,

$$\frac{D}{L} \propto (We)_c^{-\frac{2}{3}}\ (P_{No})^{-\frac{2}{3}}\left(\frac{L^3}{v}\right)^{-\frac{2}{3}} \quad \ldots.(22)$$

Hinze [7] has pointed out that the maximum drop diameter observed by Clay [8] in the dispersion of oil in water between rotating and stationary coaxial cylinders conforms with the $\frac{2}{5}$ exponent of the power input as predicted by equation 22.

Vermeulen [9] dispersed a number of two liquid systems in a fully baffled tank with a paddle stirrer under conditions where (P_{No}) and $\left(\frac{v}{L^3}\right)$ were both constant, and found

$$D/L \propto f_\varphi(We)_c^{-\frac{2}{3}}$$

thus confirming the $\frac{2}{5}$ exponent of the Weber number predicted by equation 22.

The factor f_φ in Vermeulen's empirical equation was found to depend on the dispersed phase hold-up and is given by

$$f_\varphi = 2.5\ H + 0.75$$

The latter expression is reminiscent of the Einstein equation for the viscosity of dilute suspensions which takes the form

$$\frac{\mu_s}{\mu_c} = 2.5\ H + 1$$

where μ_s = viscosity of suspension. It is therefore possible that f_φ is a concealed viscosity ratio parameter. Equation 22 may be simplified to give,

$$D = C_2\left[\frac{\sigma^{\frac{3}{5}}}{\left(\frac{P}{v}\right)^{\frac{2}{5}}\rho_c^{\frac{1}{5}}}\right] \quad \ldots.(23)$$

where C_2 is a constant which for the data of Clay [8] is approximately 0.725 cm and for that of Vermeulen [9] approximately 0.07 cm, if in the latter case a Power number of 2 is assumed. From this one must conclude that the baffled tank and agitator is a much more efficient means of dispersion than the Couette coaxial cylinder arrangement.

For the dispersion of gases in liquids using the same equipment as above, Vermeulen finds

$$\frac{D}{L} \propto f_\varphi\ (We)_c^{-\frac{2}{3}}\ (N_{Vi})_c^{-\frac{1}{2}}\left(\frac{\mu_d}{\mu_c}\right)^{-\frac{1}{2}}$$

where $(We)_c = N^2L^3\rho_c/\sigma$
and $(N_{Vi})_c = \mu_c(L\sigma\rho_c)^{-\frac{1}{2}}$

The introduction of the viscosity parameters above is perhaps unexpected in view of the fact that viscous forces in gas dispersion would be expected to be negligible. However, it is well known that gas dispersion considerably reduces the power dissipation and discharge velocity of agitators. This reduction in agitation level may well mean that the Power number enters the region where it is strongly dependent on the Reynolds number or viscosity giving from equation 22, a dependence of D on the viscosity.

Discussion

For gas dispersion where viscous forces in the dispersed phase are small and for liquid-liquid dispersion under mild turbulent conditions, a constant Weber number characteristic of the dispersion equipment would be expected to relate the maximum bubble or drop size with the flow rate or agitator tip velocity, the density and the interfacial surface tension. (Equations 16 and 22.)

For severe conditions of dispersion, viscous forces may predominate over those due to surface tension and a constant Reynolds number may be found most appropriate. (Equations 13 and 20.)

In the general case both viscosity and surface tension forces have to be taken into consideration. If we say that for a given hydrodynamic situation, dispersion occurs when a critical value of the ratio (inertia forces)/(surface tension + viscous forces) is reached, we obtain the result

$$(We)/(We)_{[N_{Vi}=0]} = \{1 + C_3(We)^{\frac{1}{2}}(N_{Vi})\} \quad \ldots.(24)$$

and where $(We)_{[N_{Vi}=0]}$ is the critical Weber number when viscous forces are absent (See Equations 14 and 21) and C_3 is a constant. N_{Vi} is a rough measure of the relative magnitudes of viscous and surface tension forces and is given by $\mu_d/(D\sigma\rho_d)^{\frac{1}{2}}$.

Suppose that for a given class of dispersion equipment we have correlated drop or bubble size data for conditions where N_{Vi} is small (Equation 16 or 22) and thereby evaluated $(We)_{[N_{Vi}=0]}$. It should then be possible by means of equation 24 to calculate (We) for finite values of (N_{Vi}) (i.e., for all conceivable kinds of dispersions), from a few experimental results with selected systems for which N_{Vi} is finite thus establishing the value of the constant C_3.

In this connection Hinze [7] has given some results showing $(We)/(We)_{[N_{Vi}=0]}$ plotted against N_{Vi} for the breakdown of a liquid drop in an air stream.

Much experimental work remains to be done in this field. A start is being made by the author and others at the Chemical Research Laboratory, D.S.I.R., to examine equation 22 which applies to the dispersion of gases in liquids with agitators in baffled tanks. Gas bubble sizes are to be determined by the light-scattering technique developed by Clark,[10] Vermeulen [9] and Trice [11] and power characteristics by conventional dynamometers. The results are expected to be of particular interest to those concerned with the design of fermentation equipment.

(To be continued)

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VAPOUR LIQUID EQUILIBRIUM AT LOW CONCENTRATIONS

Acetic Acid Water; Nitric Acid Water

by S. R. M. ELLIS, Ph.D., and E. BAHARI, Ph.D.*

THE acetic water system has been investigated by several workers[1-5] in a variety of equilibrium stills. Brown and Ewald[1] have reported results for a concentration as low as 2.1×10^{-6} mole fraction water in acetic acid. Little information exists for nitric-acid water and particularly so at concentrations below 0.01%.

The object of this investigation has been to determine the vapour liquid equilibrium for low concentrations of acetic acid and of nitric acid in water and for low concentrations of water in acetic acid.

Equilibrium Still

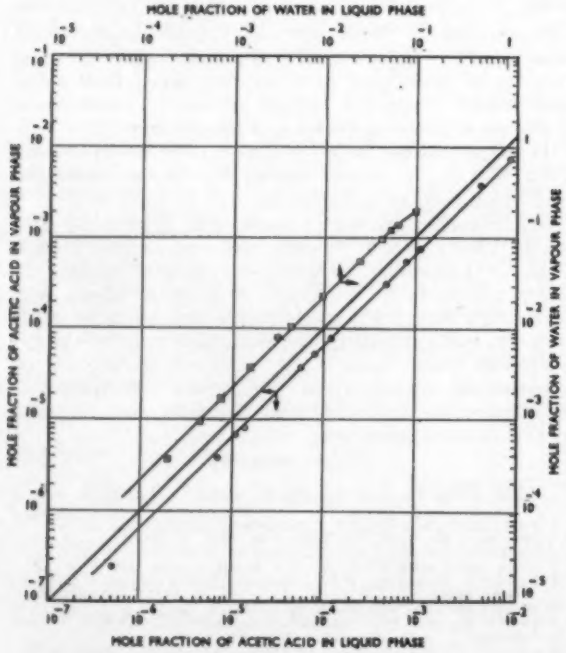
A recycling still of the type described by Thwaites[6] was used for aqueous and other systems requiring a high heat input. For tests on concentrated acetic acid mixtures where a high input was not required the still of Ellis[7] was used. These stills are of essentially the same design although the latter has a lower heating capacity and for aqueous mixtures requires a larger heating unit.

Analysis

At low concentrations of acetic acid and nitric acid in water the analysis was determined conductimetrically by means of a conductance bridge which gave reproducible results in the range of 3×10^{-5} to 1.0 mole per cent acid.

In the range of concentrations above 90 mole per cent acetic acid the samples were analysed for water by means of the Karl Fischer[8] titration conforming to the specifications of the "British Standards 2511 : 1954—Part I". Repro-

* Chemical Engineering Department, The University, Birmingham.


MOLE FRACTION OF WATER IN LIQUID PHASE
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MOLE FRACTION OF WATER IN VAPOUR PHASE
MOLE FRACTION OF ACETIC ACID IN LIQUID PHASE

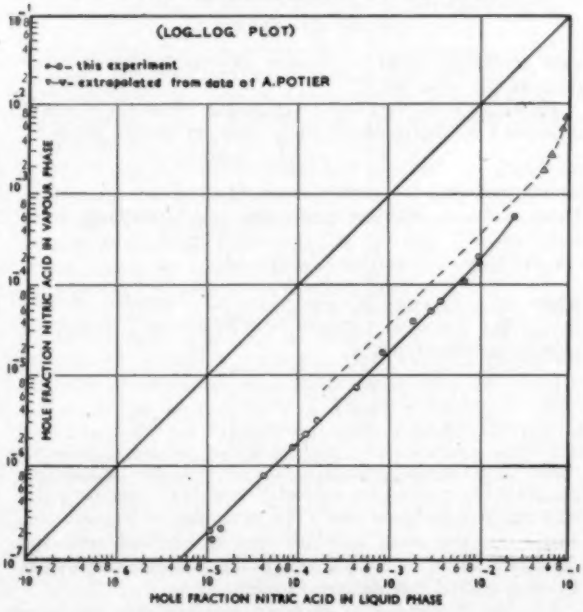
(LOG_LOG PLOT)
o-o- this experiment
v-v- extrapolated from data of A.POTIER
MOLE FRACTION NITRIC ACID IN VAPOUR PHASE
MOLE FRACTION NITRIC ACID IN LIQUID PHASE

Fig. 1. (*left*) *Vapour liquid equilibrium data on acetic acid water system. Fig.* 2 (*below*) *Equilibrium data on nitric acid water system at atm. pressure.*

ducible results were obtained by this method for water concentrations ranging from 0.03 to 35 mole per cent water. For samples containing less than 1 mole per cent water two titrations per sample were made to check the accuracy of the analysis.

Sampling techniques were developed in order to protect the samples from atmospheric moisture. In the analysis of samples from the equilibrium still sample bottles fitted with transclucent latex vaccine caps were used. The sample was run into the bottle by means of a hypodermic needle fitted to the sample line and pierced into the bottle through the vaccine cap. The bottle was vented by means of another hypodermic needle connected to a drying tower. The bottles were dried by circulating dry air through them just before sampling. The vaccine caps had the property of maintaining a good seal even after being pierced several times. The transfer of samples into the titration vessel was made by means of hypodermic needles.

TABLE 1.

Vapour-Liquid Equilibrium Data on Acetic Acid Water System. Low Water Concentration Range.

T°C	P	x_w	y_w	x_a	y_a	P_w	P_a	γ_w	γ_a	$\log\gamma_w$	$\log\gamma_a$
117.05	752.0	0.00020	0.00036	0.99980	0.99964	1360	730	0.995	1.03	−0.0022	0.0128
117.30	755.5	0.00046	0.00096	0.99954	0.99904	1370	735	1.19	1.03	0.0755	0.0128
117.30	755.0	0.00075	0.00163	0.99925	0.99837	1370	735	1.20	1.03	0.0792	0.0128
117.00	751.3	0.00152	0.00375	0.99848	0.99625	1355	730	1.37	1.03	0.1367	0.0128
116.90	751.7	0.00314	0.00810	0.99636	0.99190	1350	725	1.24	1.03	0.0934	0.0128
116.80	751.0	0.00457	0.01067	0.99543	0.98933	1350	725	1.30	1.04	0.1139	0.0170
116.45	750.0	0.0099	0.02330	0.99010	0.9765	1330	715	1.34	1.04	0.1271	0.0170
115.40	746.3	0.0242	0.0560	0.97580	0.9440	1285	690	1.35	1.05	0.1303	0.0212
114.55	751.5	0.0437	0.0996	0.9563	0.9004	1250	675	1.40	1.05	0.1461	0.0212
113.80	746.7	0.0552	0.1245	0.9446	0.8755	1220	655	1.38	1.06	0.1399	0.0253
113.20	745.3	0.0659	0.1385	0.9341	0.8615	1190	645	1.32	1.06	0.1206	0.0273
112.00	748.0	0.1020	0.200	0.8980	0.800	1145	620	1.28	1.07	0.1072	0.0294
111.50	752.3	0.1303	0.249	0.8679	0.751	1125	608	1.28	1.07	0.1072	0.0294
110.55	750.8	0.1560	0.288	0.8440	0.712	1090	590	1.27	1.07	0.1038	0.0294
109.80	753.0	0.1920	0.335	0.8074	0.665	1060	575	1.24	1.08	0.0924	0.0326

TABLE 2.

Vapour-Liquid Equilibrium Data on Acetic Acid Water System. High Water Concentration Range

T°C	P	x_w	y_w	x_a	y_a	P_w	P_a	γ_w	γ_a	$\log\gamma_w$	$\log\gamma_a$
99.2	727	0.9880	0.9921	1.2×10^{-2}	7.9×10^{-3}	742	405	0.985	1.190	−0.0066	0.0719
99.3	730	0.9944	0.9961	5.6×10^{-3}	3.9×10^{-3}	745	405	0.982	1.255	−0.0079	0.0983
99.2	737	0.99884	0.99922	1.2×10^{-3}	7.8×10^{-4}	740	405	0.996	1.227	−0.0017	0.0889
98.6	722	0.99918	0.99945	8.2×10^{-4}	5.5×10^{-4}	725	400	0.995	1.210	−0.0022	0.0828
98.6	725	—	—	4.9×10^{-4}	3.1×10^{-4}	730	400	0.996	1.150	−0.0017	0.0607
98.6	726	—	—	1.2×10^{-4}	8.0×10^{-5}	732	400	—	1.210	—	0.0828
98.9	730	—	—	8.0×10^{-5}	5.4×10^{-5}	735	400	—	1.220	—	0.0864
98.8	725	—	—	5.6×10^{-5}	3.8×10^{-5}	732	400	—	1.230	—	0.0899
98.8	724	—	—	1.4×10^{-5}	8.0×10^{-6}	732	400	—	1.030	—	0.0128
98.8	725	—	—	1.1×10^{-5}	6.8×10^{-6}	732	400	—	1.120	—	0.0492
98.9	728	—	—	6.8×10^{-6}	3.9×10^{-6}	732	400	—	1.040	—	0.0170
98.0	730	—	—	4.9×10^{-7}	2.5×10^{-7}	740	405	—	0.930	—	−0.0314

TABLE 3.

Vapour-Liquid Equilibrium Data for the System Nitric Acid Water at Low Concentrations of Acid.

Test No.	T°C	P mmHg	x_a	y_a	x_w	Pn mmHg	Pw mmHg	γ_a	γ_w
1	99.45	751.8	1.2×10^{-8}	1.65×10^{-7}	—	1260	750	.0082	—
2	99.35	749.0	1.13×10^{-8}	2.0×10^{-7}	—	1255	745	.0107	—
3	99.4	748.8	1.52×10^{-8}	2.1×10^{-7}	—	1260	750	.0084	—
4	99.6	755.0	4.5×10^{-8}	7.5×10^{-7}	—	1265	750	.0099	—
5	99.2	745.6	9.2×10^{-8}	1.7×10^{-6}	—	1250	745	.011	—
6	99.75	759.0	1.3×10^{-4}	2.4×10^{-6}	—	1270	755	.012	—
7	99.7	750.3	1.7×10^{-4}	3.5×10^{-6}	—	1270	755	.012	—
8	99.3	745.2	4.7×10^{-4}	0.8×10^{-6}	—	1250	745	.010	—
9	99.75	757.4	8.9×10^{-4}	1.9×10^{-5}	—	1270	755	.013	—
10	99.4	754.0	1.9×10^{-3}	4.2×10^{-5}	.9981	1260	750	.013	—
11	99.55	748.0	3.0×10^{-3}	5.6×10^{-5}	.997	1263	750	.011	—
12	99.8	753.8	3.9×10^{-3}	7.3×10^{-5}	.996	1275	755	.011	—
13	99.9	753.0	7.2×10^{-3}	1.2×10^{-4}	.993	1280	760	.01	.99
14	99.6	735.0	1.06×10^{-2}	1.9×10^{-4}	.989	1265	750	.010	.98
15	100.4	735.0	1.05×10^{-2}	2.3×10^{-4}	.989	1300	755	.013	.97
16	100.9	751.0	2.6×10^{-2}	6.1×10^{-4}	.974	1320	790	.013	.95

Acetic Acid Water System

The experimental results covering a composition range of 0.9998 to 5×10^{-7} mole fraction acetic acid are summarised in Tables 1 and 2. Boiling points (T°C), liquid and vapour compositions (x, y), vapour pressure data (P) and calculated activity coefficients (γ) are given.

Fig. 1 gives a log-log plot of the equilibrium data. Below a water concentration of $x_w=0.006$ and an acid concentration of $x_a=0.01$ the plot is a straight line and parallel to the 45 degree line.

The results for a low concentration of water in acetic acid are in close agreement with those of Brown and Ewald[1].

Nitric Acid Water

The experimental results for a low concentration of nitric acid in water are given in Table 3. The x-y data is shown in Fig. 2 and for an acid concentration range of 10^{-6} to 10^{-2} the plot is a straight line parallel to the 45 degree line.

With such information available it is thus possible to assess stray efficiencies in the dehydration of acetic acid and in the removal of traces of acetic acid or nitric acid from water.

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Underground Gas for Power Generation

THE possibilities of the large-scale exploitation of underground gasification are to be investigated under the joint auspices of the National Coal Board and the Central Electricity Authority. Announcing this in the House of Commons, the Minister of Fuel and Power, Mr. Aubrey Jones, said he had indicated to both authorities the importance of developing with the utmost expedition this important new technique, as well as his wish that private enterprise should be associated in it, so that full advantage of its successful development can be taken in overseas markets. It is envisaged that a new pilot plant will be designed to use gas produced underground to drive an electric generator. According to the Ministry's report (*British Trials in Underground Gasification*, 1945-1955, H.M.S.O., 8s.) the trials so far carried out in this country justify the conclusion that useful gas can be produced by a variety of methods of underground gasification and that this gas is capable of being harnessed to electrical generators.

Coal has already been gasified in Britain at rates of over 20 tons daily, which should be sufficient to generate power up to 800 kilowatts. So far no trial has included electrical generation, and a new pilot plant will be required in order to test the feasibility of using underground coal as fuel for an electric power station. To obtain firm figures of operating costs, the pilot installation should gasify at least 50 tons of coal a day. One London firm which is keenly interested in the industrial development of underground gasification is Cementation Ltd., which recently formed a satellite company called Coal Gasification Ltd. The Americans and the Russians are also reported to have done a good deal of work on this technique.

A corrosion-resistant loading deck suitable for heavy duty trucking under construction; the cast-iron grid is being filled with an anti-corrosive cement.

CHEMICAL-RESISTANT FLOORING

by F. C. HARPER B.Sc., Ph.D.*

THE primary purpose of a floor-finish in an industrial building is to protect the structural floor from the factory conditions; i.e. from foot and truck traffic and from corrosive effluents. The structural floor is usually constructed of some form of concrete and it is with the protection of concrete floors that this article deals.

If the factory is dry, the floor finish has to withstand only foot and truck traffic and a good-quality concrete floor is adequate. If the process is wet, many problems arise in protecting the concrete base. Attention will be directed to these problems as they relate to suspended concrete floors because they are the more likely to become dangerous if attacked; much of what is said, however, applies with slightly less force to solid concrete floors. It is not intended to give more than an outline of the principles involved in the design of corrosion-resistant floors and their details of construction.

The floor system in most factories comprises a structural load-carrying floor, usually with a screed, and with a wearing finish. The structural floor and screed together will, for convenience, be called the sub-floor and are assumed to be constructed from normal or rapid-hardening Portland cement.

Portland cement, and therefore concretes made from it, are attacked by acids (except in low concentration), by some organic materials containing hydroxyl groups, and by animal and vegetable oils. They are susceptible to attack by solutions of sulphates when calcium sulphoaluminate is formed. They are resistant to alkalis, to solvents and to water.

The risk of corrosion of steel reinforcement must also be considered. If acids or salts can reach the steel it will inevitably corrode. A good cover of high-quality concrete is the normal method of protecting structural steel from corrosion, but if the liquids are also corrosive to concrete other forms of protection are needed. It should be particularly noted that solutions of common salt, which do not attack concrete, may reach steel reinforcement and produce corrosion. Liquid-tight protection is, therefore, indicated.

When the conditions above the floor-finish are highly corrosive a fully protective construction is essential; where the floor finish is attacked slowly, various less protective constructions are available and they must be chosen by balancing their life against their cost. It is impossible to generalise on this topic because of the number of variables involved. Often experience of similar constructions in various conditions must be sought before a decision is made.

In providing a corrosion-resistant floor there are two equally important factors to be considered: the design of the floor as a whole and the type of the floor finish.

Design of the Floor

It is seldom that the plant is tailored to meet the floor problems, and the floor design must take account of all kinds of conditions. Obviously the best, but often overlooked, method of preventing corrosion is to prevent spillage of corrosive liquids from reaching the floor finish. It is worth while to arrange catch-pots at all possible drip points, but even in the best-run and designed of plants some spillage must occur, if only by accident. It is advisable, for reasons of cost, to group the spillage points so that the area requiring maximum protection may be kept to the minimum. In the same way, if service pipes

*Building Research Station.

must break the continuity of the floor-finish, they should be grouped in a conduit, as a seal round a large hole is likely to be better than several small seals.

The greatest single precaution against corrosion is to provide adequate drainage. No matter how well a floor finish has been laid there are usually some low-spots which will collect liquors and become centres of corrosion. To avoid this, the floor-finish should be sloped, and the steeper the slope of the finished floor the better the drainage. However, the steeper the slope the greater is the risk of accidents by slipping and by runaway trucks; therefore a balance must be made. If the surface be smooth and there is little spillage, a slope of 1 in 80 may be considered as the minimum; as unevenness and the amount of spillage increase the slope must be increased up to 1 in 40, which must be considered a maximum if the floor is to be used by traffic.

The method of providing the slopes is controlled primarily by the positioning of the drains, which are usually sited according to the following principles. They should be close to the main source of spillage; far from sources of vibration; far from any load-carrying member which might be damaged should they leak; and easily accessible for examination and repair. To meet these often conflicting requirements the floor may be sloped in one or a combination of three ways.

Transverse slope: the floor slopes from each side of the building to a central drain running the length of the building. This type of slope should never run from the centre to two channels along the walls.

Longitudinal slope: the floor is in a series of slopes with channels running across the building but not as far as the walls.

Saucer slope: the floor is divided into a series of rectangular dishes discharging into a central drain.

It is impossible to provide the necessary falls in the thickness of the floor finish; therefore the sub-floor must be so constructed as to give the correct contours.

Even when the correct falls have been provided, detailed consideration must be given to the possibility of obstructions and openings in the floor finish causing undrained pockets. All openings should have a curb 6 in. high around them and these curbs and all other projections should be so placed with respect to the slope that they present the minimum resistance to the flow of liquid.

Some materials used as finishes are such that they prevent liquids reaching the base floor; others are permeable. Even the impermeable finishes are liable to allow penetration of liquid, through some minor defect of workmanship or by some thermal or structural movement. Penetration of corrosive liquids through a resistant floor finish is most dangerous. Here the finish is unattacked while, unseen below it, the sub-floor is slowly damaged. It is good practice to provide a liquid-tight layer below the resistant finish as a second line of defence. The underlay should be resistant to the liquids of the process and should be impervious to them. It should be slightly flexible but able to support the loads applied to it withou breaking down; obviously it need have no resistance to wear. The membrane should be laid after the fall has been produced on the sub-floor, so that, should liquids penetrate the floor finish, they will flow to the drains and not to the walls. It is essential that it should be continuous and great care should be taken to ensure this continuity around drains and at holes in the floor.

The commonest underlay is acid-resistant asphalt which, to prevent cracking, is often laid on a layer of saturated felt and is thus isolated from the sub-floor and does not move with it. The thickness of the asphalt should be not less than ¾ in., laid in two layers with all construction joints broken. It should not, however, be used where reliance must be placed on a joint to steelwork because it is not possible to guarantee a liquid-tight seal at such a joint.

Bituminous felt has been used successfully when laid with 3-in. lap joints carefully sealed with hot bitumen. It is not easy to work the material round sharp corners and in these situations it is used in conjunction with asphalt.

Probably the cheapest, but the least widely applicable method, is to use three or four layers of tarred paper with overlapping edges and with the sheets in alternate layers at right-angles to one another.

Recently, thin films of polyethylene and polyvinyl chloride have been used as underlays in very corrosive situations. Very thin films are used, the polythene being between 0.004 and 0.020 in. thick. There are obvious difficulties in avoiding punctures in a film as thin as this, and the finish of the sub-floor must be smooth enough to prevent any danger of the film being ruptured when the floor finish is laid on it. The cost of the material, and of the careful laying necessary, restricts the use of the film to situations where there is no alternative available.

Opinions differ on whether the underlay should be fixed to the sub-floor. It may be argued that a loosely laid underlay will not crack if the sub-floor cracks or moves. On the other hand all the edges of the underlay must be sealed to the walls so there is a danger of the underlay tearing with structural movement.

With all these precautions it is wise to arrange that the underside of the structural floor be accessible for inspection; some plants constructed at ground level have been provided with basements for this purpose. If the underside of the floor is whitewashed any penetration can be seen quickly and this is a far better guide to failure of the protective flooring than is a surface examination.

Materials for Finishes

As has already been noted, a completely resistant finish is clearly necessary if the conditions are very corrosive, but the choice of finish is more difficult if there is slow attack by a mildly corrosive reagent. In conditions of mild attack a concrete finish may last for several years and, if dense enough, will protect the floor below it. Eventually, however, it must require patching and, finally, renewal, with the attendant disorganisation of production. The designer, therefore, faces the problem of whether to use a concrete finish and replace it from time to time, or to use a finish that will eliminate maintenance costs but at a very much higher initial cost.

The choice of finish is influenced by installation cost, estimated maintenance and renewal cost, and by the resistance to corrosion and wear. The variation of conditions in factories and their different economic backgrounds makes any generalised statement impossible. The most that can be done here is to list the various materials in roughly rising order of cost and to give a broad indication of their properties.

The Table indicates the resistance of different jointless floor finishes and of bedding and jointing materials to various liquids and solutions. The materials are in rising order of cost. Where possible the resistance is given in the form of a number but where this is impossible a five-point evaluation is used; VG=very good; G=good; F=fair; P=poor; VP=very poor. The Table is intended for broad comparisons as the items under the various headings may need qualification for particular conditions.

Jointless Floor Finishes

The following notes are supplementary to the information given in the Table at the bottom of page 214.

Concrete made with Portland cement: The valuation in the Table assumes a concrete of good quality and high density, made from normal Portland or rapid-hardening Portland cement. Recently, sulphate-resistant Portland cement with greater resistance to sulphates has become available.

The rate of attack of concrete depends on the quality of the material and a good quality material may be expected to have a fair life in mildly aggressive liquids. The initial planning of a floor for such circumstances should take account of its eventual replacement. When concrete is laid as a topping on a new concrete base it is usually only ¾ in. thick, but when concrete is laid on an old base a layer of 1½ in. and preferably 2 in. is necessary. Thus it may be found on replacing a concrete floor that the levels of the plant must be altered to make a satisfactory finish. Initially, therefore, concrete floors should be laid about 2 in. thick.

Concrete made with high-alumina cement: Again a high quality material is assumed in the evaluation. A floor finish made of high-alumina cement must be kept wet for 24 hours after laying as considerable heat is evolved during setting and the mix would dry and crack if more water were not applied. At temperatures above 85°F, and particularly in wet conditions, high-alumina cement loses strength and becomes more porous. This increase in porosity will probably increase the rate of attack by materials which attack the unaltered cement.

Although only slightly better than Portland cement, its resistance to acid is enough to make its use preferable in conditions of mild attack, e.g., in dairies. However, its lack of resistance to alkalis is a disadvantage.

Mastic asphalt: Mastic asphalt is normally made with a limestone filler but special grades with siliceous fillers are available for use in corrosive conditions. These grades are resistant to acid concentrations above *p*H 1 and all concentrations of alkali. However, oxidising and halogenating reagents may react with the bitumen, particularly at high temperatures. Not all bitumens are attacked in this way, therefore the advice of an asphalt specialist should be sought when severe conditions are expected. Asphalt floors are not resistant to oils, fats, greases or solvents, nor are they particularly suited to very hot conditions. Their outstanding merit is their complete impermeability to liquids.

Pitch mastic: Generally similar to their asphalt counterparts, pitch mastic floors are more resistant to oils and greases. There is, however, little experience of their use in corrosive conditions.

Rubber-latex cement: Rubber-latex cement floors are essentially a mortar made with Portland or high alumina cement and mixed with rubber latex. The resistance to acids and alkalis depends on the hydraulic cement used and the values in the Table are given with different cements in mind. Outside the safe range, however, the rate of attack of these compounds is less than that of an ordinary cement mortar because of the protective action of the rubber. The rubber constituent is attacked by oil and grease but the use of synthetic latexes avoids this. Owing to the presence of rubber, the floors should not be used for resistance to caustic alkali.

Synthetic-resin emulsion cement: Resin emulsion cement floors differ from latex cement floors in that they contain a plasticised polyvinylacetate emulsion instead of rubber. This gives the floor resistance to oil, but a lower resistance to abrasion in wet conditions.

All the floors mentioned are laid *in situ* and are the only such floors that are corrosion-resistant. The "chemical" acid-resistant cements cannot be used in jointless flooring and are intended only as a tile jointing.

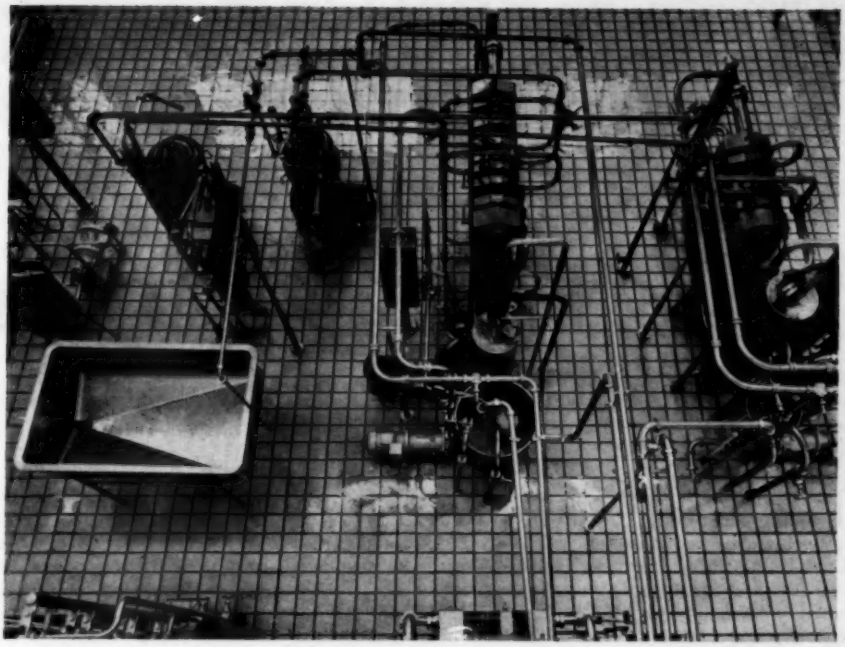
Jointed Floor Finishes

Clay tiles or bricks are the only materials that can be used in jointed floor finishes intended for corrosive conditions, and are more used than any other flooring material. For best results they should be of engineering quality; reds and blues differ very little in performance but yellows are more porous. Tiles less than 1 in. thick have low resistance to impact and this should be considered as the minimum thickness. On balance the best

Table 1: The resistance of jointless floor finishes and of bedding and jointing materials to various liquids.

	Water	*Satisfactory pH Range*	*Organic Acids*	*Hydrochloric Acid*	*Sulphuric Acid*	*Nitric Acid*	*Alkali*	*Sulphates*	*Mineral Oil*	*Animal Oil*	*Organic Solvents*
JOINTLESS FLOOR FINISHES											
Portland Cement Concrete	VG.	7-12	P.	VP.	VP.	VP.	G.	P.	G.	P.	G.
High Alumina Cement Concrete	G.	5-9	G. if pH>7.5	VP.	VP.	VP.	F.	G.	G.	F.	G.
Pitch Mastic (depending on grade)	VG.	1-11	G.	G.	F.	F.	G.-F.	VG.	F.	F.	P.
Mastic Asphalt (depending on grade)	VG.	1-11	G.	G.	F.	F.	G.-F.	VG.	P.	P.	P.
Rubber Latex Cement	G.	7/12 but better than mixes without latex outside range	G-F.	G. to 5% then P.	G. up to 5% then P.	G. up to 5% then P.	G.	F.-G.	F.-G.	F.	P.
Resin Emulsion Cement	F.	◄ not particularly suitable in wet conditions ►							G.	F.	G.
BEDDING AND JOINTING MATERIALS FOR CLAY TILES AND BRICKS											
Portland Cement Mortar	as above for concrete										
Super Sulphate Cement Mortar	VG.	3-12	G.	up to 0.5%-G. then P.	up to 1.5%-G. then P.	F-P.	G.	G.	G.	G.	G.
High Alumina Cement Mortar	as above for concrete										
Silicate Cement	P.	0-7	G.	G.	G.	G.	VP.	G.	G.	G.	G.
Sulphur Cement	VG.	0-10	G.	G.	G.	Dilute-G. Concentrated-F.	G.	G	G.	P.	G.
Rubber Latex Cement	as above for jointless flooring but attack is slower in a thin joint										
Phenol Formaldehyde Cement	VG.	0-10 greater if specially modified	G.	G.	Dilute-G. Concentrated-F.	Dilute-F. Concentrated-P.	G.	G.	G.	G.	G.-P.
Cashew Nut Resin	VG.	0-12	G.	G.	Dilute-G. Concentrated-F	10%-G. 50%-F. Concentrated-P.	G.	G.	P.	P.	P.
Furane Resin	VG.	0-12	G.	G.	G. up to 60%	up to 3-4% cold 2% hot	VG.	G.	G.	G.	G.

Ranges given as pH=o-x indicate that, apart from specific action by acids which are oxidising agents, the material resists all concentrations of acids.



A floor at N.I.Z.O., the Dutch dairy research centre at Ede. The tiles are painted with a cement that is unaffected by lactic acid.

dimensions of face are 6 in. x 6 in.; 9 in. x 4½ in.; 9 in. x 6 in., or 9 in. x 9 in. Paviors for flooring are usually 9 in. x 4½ in. x 2 in. and made without a frog. They are usable either face up, edge up or, infrequently, end up.

To avoid slipperiness the surfaces may be roughened by a geometrical pattern of grooving or by random roughening as in the finish known as "shot-blast". This latter cannot be expected to remain rough under the action of heavy trucking. It is suggested that a better way of reducing slipperiness is to keep the surfaces scrupulously clean.

The properties of the various cements that can be used to bed and joint a tiled floor are given in the Table. The following notes are supplementary to the Table.

Portland cement: Portland cement is used with sand in the proportion 1:3 with a low amount of water added. Adequate adhesion to tiles. Joint not liquid-tight.

Supersulphate cement: Supersulphate cement is handled in the same way as Portland but in rather richer mixes. The mortar must be kept damp for some days after laying. Its resistance to acid is greater than that of high-alumina cement and it has high resistance to sulphates. The joint is not liquid-tight.

High-alumina cement: Again a cement-sand mortar is used and the same precautions should be taken as for high-alumina concretes. The joint is not liquid tight.

Silicate cement: The cementing material is silica gel mixed with inert filler. The silica gel is deposited from sodium silicate by sodium silicofluoride or ethyl acetate, or from silicon ester by water. After setting, the cement should be washed with dilute acid or the alkali formed during setting may subsequently destroy the joint. Silicate cements are the only cements which will withstand hot strong mineral acid (except hydrofluoric), but they are attacked by weak alkali and by water. The serious disadvantage is that liquids can penetrate the joints by capillarity. Thus a flooring jointed with silicate cement needs an underlay.

Sulphur cement: Molten mixtures of sand and plasticised sulphur are poured into wide spaces between tiles to give a good joint. The joint is resistant to acids (except concentrated nitric and sulphuric), to water and to alkalis, but is attacked by vegetable oils, some solvents and by a sulphur-oxidising bacteria. Temperatures of 95°C should not be exceeded as there is an inversion point at 96°C.

Rubber-latex cement: Rubber-latex cement mortars adhere very tightly to tiles, and joints made from them have similar properties to the jointless floors already described. The joints have, on occasion, been found to be satisfactory when failure might have been expected. It is suspected that when acid has etched away the cement the remaining rubber and sand swell and give a liquid-tight seal across the top of the joint.

Phenol-formaldehyde resin cements: Joints of phenol-formaldehyde are prepared by acid-catalysing a resin syrup. Although cold setting, the strength of the joint is increased when heated. The joints are liquid tight and resist all but oxidising acids and concentrated alkalis. They should not be heated above 180°C.

Cashew nut resin cement: A syrup of substituted phenols from cashew nuts is catalysed by paraformaldehyde to give a flexible cement resistant to acids other than hot oxidising acids. It offers good resistance to caustic alkalis. The resistance to solvents is low. The joint is liquid tight.

Furane resin cement: Furane resin mixed with fillers is catalysed to give a hard solid joint resistant to alkalis, solvents and all but concentrated oxidising acids. Its properties are broadly those of phenol-formaldehyde cements but it is easier to handle and it requires no heat treatment.

The laying of tiles and bricks in any of these cements is a specialised operation and the success of the final floor depends to a large extent to the attention given to the details of setting-out. It cannot be too strongly emphasised that skilled workmen be used for the work.

It is obvious that a completely corrosion-resistant floor is an elaborate construction. All machine bases and services must be in position before laying begins. It is a major undertaking to move plant at a later date as punching holes in the floor may ruin the whole system. For these reasons an elaborate corrosion-resistant floor should be used only where the factory process is likely to continue for some considerable time. If there are to be frequent plant alterations it is better to use a simple floor system and replace it as necessary.

(Photos by Acalor (1948) Ltd.)

REDUCING LABOUR COSTS IN CHEMICAL AND PROCESS INDUSTRIES

by CHRISTOPHER J. PRATT, M.I.Chem.E., A.M.I.P.E.

IN many cases, the labour cost involved in chemical and process work is relatively low; figures of 5-10% are sometimes quoted for specific processes, compared to a general industrial average of some 40%. However, this should never be regarded as an excuse for complacency when considering possible ways of reducing the labour cost of any chemical or process operation. This particularly applies to shift labour necessitated by a continuous process, which can result in a yearly wage bill of considerable size. A reduction of only a few per cent in labour cost may yield appreciable annual savings and, furthermore, the saving of only one man on an operation may mean a saving of three or even four men when shift work is necessary. This is of additional value when labour is scarce, or when a few experienced men are needed to make up a team for a new plant section.

Labour savings are frequently thought to be the province of the Work Study Engineer, based upon his observations in the plant, but owing to the complexity of many processes and the non-visible nature of numerous operations in this type of industry, worthwhile labour savings cannot, as a rule, be made entirely on the basis of quick time studies. Still less can they result only from occasional flashes of inspiration or hunches on the part of the management.

Instead, a careful analysis of each item likely to affect labour costs should be made by a management team on the lines suggested in this article. Failure to give adequate consideration to each factor may result not only in a potential source of labour savings being overlooked, but the effect on quality and output induced by the proposed changes may remain problematical, instead of being known in advance.

Labour Costs and Related Factors

Quite often an approach to labour cost reduction is made solely in terms of improvements to methods and ancillary equipment, without any serious consideration being given to the main fundamental items of the organisation. These are generally considered to be:

i Primary and secondary materials;
ii Capital equipment and related overhead items;
iii Direct and indirect labour.

However, depositing a pile of material on a factory floor, engaging some labour and providing a battery of expensive machines will not result in much saleable production. Hence, it is proposed to add two further, but less tangible items, namely:

iv Administrative functions;
v The human factor.

For costing purposes, items iv and v are usually combined with iii. It is probable that this line of thinking has, until recent times, tended to mask their great importance, and a large price continues to be paid for trying to run organisations on the basis of a costing convenience. Accordingly, these five items will be separately considered in relation to their influence on labour costs as applied to process operations.

Influence of Primary and Secondary Materials

An analysis of the operations involved in a process may show that relatively little labour is occupied in handling and dealing with the materials used, the work in progress or secondary products such as waste precipitates, scrap, packaging items and samples. On the other hand, these operations may comprise a considerable part of the total labour required, so that a detailed consideration of such work may well be worthwhile.

In cases of this kind, it is quite likely that elementary questions concerning the elimination of reduction of one or more of the materials concerned in the process have never been asked, on the grounds of apparent absurdity or impossibility. Similarly, the idea of using one or more of the materials in an alternative form has never been explored, because of lack of specific data, or for fear of affecting established customs and quality standards, or perhaps purely for reasons of conservatism. However, changes are sometimes made imperative because of material shortages, price factors or product modifications, quite apart from a search for economies; in some instances of this type, labour savings have resulted more or less fortuitously. Some typical cases where a change in materials has also lead to a labour cost reduction are as follows:

i For many years, a certain process employed a carefully prepared fresh starch solution to act as a flocculant. By accident it was discovered that sufficient flocculation occurred naturally, so that the cost of the starch as well as the labour required to prepare the solution was henceforth saved.
ii When the sulphuric acid shortage arose some years ago, a plant was compelled to reduce the quantity of acid consumed. By raising digestion temperatures and pressures slightly, it was found that less acid was needed, batch times could be reduced and less plant effluent treatment was necessary. This resulted in significant labour and material savings per ton of product.
iii In many paper and textile plants, full-time bleach men were formerly employed to prepare solutions of bleach-

ing powder. The use of bottled chlorine gas and modern chlorinators has, in numerous cases, eliminated this old, distasteful operation, with resultant labour savings and better control.

Many other examples of labour savings resulting from a change in the nature of materials used or involved in a process could be given, for instance, the use of flaked or powdered solids in place of lump material, the employment of catalysts to reduce reaction times, or the use of modern organic intermediates to eliminate, where justifiable, several steps in a lengthy synthesis.

Labour savings arising from a change to bulk handling and packaging are usually self-evident and such methods have been widely adopted. Not so obvious, however, are those cases where labour savings would result from materials being available in small unit packages, or previously prepared standard lots. This particularly applies to dangerous items such as bromine, phosphorus and certain organic compounds, where the supplier usually has excellent handling facilities, but the user has not. Cases are known where a slight extra cost for specially prepared materials has been greatly exceeded by the resultant savings at the user's plant. Other advantages such as increased personal safety, better quality control and reduced risk from accident or fire may also arise.

When searching for possible changes in primary and secondary materials to reduce labour costs, as with other items, flexibility of thought is essential. To stimulate the calling to mind of possible alternatives, some suggestions are given in List 1 of the Appendix.

Capital Equipment Related to Labour Costs

When properly utilised, larger and more complex equipment will, as a rule, result in decreased labour costs per unit of product, so that the general tendency is to think in terms of bigger units, automatically controlled. However, even in the larger process plants, there are often numerous ancillary operations performed which incur a relatively high labour cost, e.g., handling materials and packaging, preparing reagents and by-products or perhaps making small batches of associated compounds.

In operations such as these, a detailed investigation of the labour costs involved may indicate that substantial savings could be made by modifying or extending the capital equipment used. Naturally, the cost and depreciation of any extra equipment must be fully considered before making final recommendations and this also applies to other overhead items, such as extra supervision, maintenance and control if they arise.

When making investigations under this category, questions which may again seem apparently illogical should be asked in each case, e.g.:

i Is the operation and equipment really essential?
ii Could the scale of operations or the equipment used be profitably extended or reduced?
iii Would batch or continuous equipment be more economical from all points of view?

An example of the first case is typified by a process which used raw materials in a briquetted form; a large press being employed for this purpose on a three-shift basis. Some trials carried out against much opposition showed that a loose feed could be employed with virtually no material loss or increase in charging time. The use of the press was eventually abandoned, with resultant savings in labour, power and maintenance.

With regard to the scale of operations and the alternatives of batch or continuous equipment, many factors are concerned in the relation between operator utilisation and work load. Usually, detailed investigations based upon technical data, cost information and work-studies are necessary before the best policy can be established. For instance, some processes may be more economically operated on a batch or day-work basis than on a continuous basis, despite long held beliefs to the contrary. Similarly, cases are known where only a slight reduction in machine speed or plant throughput improved the machine/labour balance so much that labour costs fell without any reduction in daily output.

In general, the extended use of capital equipment when intelligently applied will lead to a reduction in labour cost. This particularly refers to materials handling devices, instrumentation and automatic control and modern, continuously operating plant, whether on a large or small scale.

There are economic limits to the extent of these applications, however, which frequently can only be determined in advance by a joint consideration of technical, cost and work-study data. List 2 in the Appendix illustrates some of the factors to be considered regarding possible savings resulting from modifications to the capital equipment used.

The Plant Operators

As far as the operators themselves are concerned, labour costs are directly functions of:

i The number and type of operators employed.
ii The hours worked and the wages paid.
iii The productivity indices of each individual and group.

These elementary factors are related to each other in a simple manner; nevertheless, they are frquently responsible for more industrial problems than ever arise from technical, financial or sales reasons. When this kind of problem develops, it is undoubtedly due to insufficient care being devoted to possible future complexities arising from *ad hoc* policies or changing conditions, and organised labour is swift to take advantage of any temporary oversight on the part of management. Other reasons for high labour costs may arise because the importance of proper administration and the human factor, as reviewed in the following sections of this article, have not been sufficiently taken into account.

First thoughts on reducing labour costs may only have concerned cutting down the number of operators employed. First considerations, however, should be directed towards eliminating some of the operations needed, or reducing them as far as possible, in frequency and degree. This may mean the introduction of new equipment, as well as the employment of a different class of labour, and sometimes a careful consideration of several cost factors such as depreciation, rate of obsolescence and maintenance is necessary before labour changes can be made and new plant ordered with confidence. Occasionally an operation can be eliminated or combined with another in a simple manner to effect a straightforward labour saving, and solutions of this nature should always be sought before developing elaborate alternatives. Detailed work-studies, using modern techniques of methods analysis and work measurement, have resulted in many substantial economies throughout all types of industries, most of them being based upon simple modifications to established procedures and not upon revolutionary changes or large capital investments.

Consideration should next be given to the type of labour employed on each operation, as regards the class of skill, sex, degree of training and wage rates paid. Not infrequently, the skill and work content of established jobs diminish because of technical improvements, yet the wage rates remain the same, or even rise considerably. Attempts to correct these anomalies may lead to industrial strife, unless expertly handled. It is for these reasons that a

FACTORS MAKING FOR LABOUR COST REDUCTION

List 1. Examples of material factors which may influence labour costs

1. Elimination of the material or a change in the amount used or produced.
2. Change of nature, e.g. to a solid, liquid or gaseous state.
3. Change in grade, quality or specification.
4. Change in form, i.e. to a powder, lump or solution.
5. Alternative packaging—drum, carboy, bulk, loose, or a standard package.
6. Alteration in temperature, moisture content, particle size, physical dimensions.
7. Combined with another material, physically or chemically.
8. Handled at another stage of the process.
9. Left in the process or removed at some stage.
10. Replaced by another material.

List 2. Some items relating capital equipment to labour costs

1. Elimination of the operation or combination with another.
2. Reduction or extension of the equipment or set-up used.
3. Increase or decrease in present capacity, speed or range of the equipment used.
4. Ganging or synchronisation of two or more items to effect redeployment of labour.
5. Installation of larger or better facilities to assist handling, feeding or take-off.
6. Improved arrangements for operating, adjusting, cleaning and maintaining the equipment.
7. Increased provision of stand-by or ancillary plant and facilities.
8. Standardisation of the major and ancillary items of equipment.
9. Extension of measuring, recording and testing devices.
10. Use of automatic control, self-feed or interlocked equipment.
11. Replacement of batch operated plant by continuously operated plant, or vice-versa.
12. Use of more modern equipment, different in principle or design.

List 3. Some factors concerning the type of labour employed and the labour costs

1. Elimination of the operation, either directly or by means of a machine.
2. Reduction of the operation performed, in frequency or degree.
3. Straightforward reduction of the number of operators engaged on the operation.
4. A change in grade, sex, type, age or physical characteristics, mental ability, etc.
5. Initial or refresher training to increase physical or mental skill.
6. Use of financial incentives such as bonus or piece work.
7. Extra awards such as long service, dirt money, merit rate.
8. Increase or reduction of indirect labour employed on ancillary operations.
9. Reduction or increase of spare labour float; reduction of labour turnover figure.
10. Use of shift labour instead of day work, or vice-versa.

List 4. Some administrative features likely to affect labour costs favourably

1. Adequacy of training and experience of management at all levels.
2. Administrative ability on the part of each supervisor, foreman and chargehand.
3. Periodic refresher courses for management and supervision.
4. Planned production and cost control. Analysis of lost time and excess costs daily.
5. Standardisation of methods and procedures on a measured work basis.
6. Co-operation from the sales department to permit better planning of work.
7. Improved assistance from functional departments, such as maintenance, stores, etc.
8. Reduction of overtime, change-overs, range of products, short runs.
9. Closer supervision to reduce bad timekeeping and lost time at all levels.
10. Periodic use of impartial outside consultants to examine procedures and recommend improvements.

List 5. Some items concerning the human factor which have a bearing on labour costs

1. The use of a skilled personnel officer to deal with details concerning wages, employee problems and working conditions.
2. The use of job evaluation to establish proper differentials of wage rates.
3. The operation of merit rating plans, to give accurate appraisals of employees and also to permit frank discussions on abilities and shortcomings.
4. The opportunity for self-expression through joint consultation, suggestion schemes etc.
5. The opportunity to earn extra money by piece work, promotion or other awards.
6. Security and stability offered through savings schemes, pension and sickness plans, etc.
7. Reasonable facilities for meals, relaxation and bodily comforts.
8. Minimisation of industrial fatigue, accident and health hazards.
9. Sound training in details of work undertaken.
10. Periodic refresher courses and reviews of employee records to stimulate the maximum interest in the work undertaken.

periodic "Job Evaluation" programme is so valuable, because it can provide the necessary facts and at the same time act as a barometer regarding changes in jobs and wage rates.

Another invaluable aid to labour cost reduction is the Productivity Index of each section and each operator. This figure relates the actual output of work produced, to the hours worked, and the data used to calculate each index can be analysed to show the precise reasons for any deviations from output and cost standards. Should the standard output not be attained or excess costs incurred, it is at once evident and the reasons can be quickly traced to their source. This offers to management a prompt, day-by-day means of control as well as measurement, which may be regarded as essential if incentive schemes are used to raise productivity. Without proper control, an incentive scheme can rapidly get out of hand and raise labour costs to an alarming degree. The Productivity Index demonstrates most forcibly that the hours of work put into any job of much less significance than the work put into those hours.

List 3 of the Appendix gives some of the items to be considered when relating labour costs to the operators employed.

Administration Factors

In any organisation, action may be said to be focused at four main levels according to the following pattern.

i Board policy is translated into management decisions.
ii Management decisions lead to supervisory instructions.
iii Supervisory instructions lead to operator activity.
iv Operator activity results in the production of goods and services.

It can be seen that a good deal of responsibility lies at each level if a complicated production programme is to be carried out with a minimum of administrative cost, misunderstanding and loss. Hence, the real reasons for any high administrative overheads and costs, low material utilisation and operator activity may originate at one or more of the higher levels of the organisation, rather than on the shop floor. It is also apparent that excess costs due to low productivity and other factors are not confined directly to operators. Indirect labour, supervision and management itself are similarly involved and, since conditions in most organisations continually change, all departments at each level should be examined from time-to-time by an impartial authority to see that the most effective use is made of the personnel employed and the facilities available. Substantial labour savings may result, indirect overheads may be reduced and general administration greatly improved, with correspondingly beneficial results on the shop floor.

One of the most valuable sources of information concerning excess costs arising from administrative shortcomings is a breakdown of the lost time booked by the operators. If such records are not already available, they should be at once instituted. Such lost time may arise from a number of causes, such as:

i Waiting for instructions, materials or equipment.
ii Stoppages caused by faulty plant or machines.
iii Poor synchronisation of inter-related jobs.
iv Too many operators or machines for the work available.
v Defective material or inadequate facilities.

When a detailed analysis is made on these lines, in conjunction with investigations into other factors, such as quality control figures, scrap, labour turnover, wage rates and piece work earnings, the real reasons for excess labour costs are usually not hard to find and may include:

i Insufficient operator training or the employment of the wrong type.
ii Weak supervision, perhaps due to lack of training or undue familiarity.
iii Lack of inter-departmental co-operation at various levels.
iv Absence of proper control methods regarding labour and production.
v Ignorance of top management concerning the true position as regards personnel, production and costs.

Administrative control in a modern technical organisation is thus seen to be a highly skilled task, for which adequate training and experience is necessary at all levels. Mere technical ability on the part of supervision, or "divine right" on the part of top management is insufficient.

Some suggested points for consideration, when reviewing the effect of administration on labour costs are given in List 4 of the Appendix.

Labour Costs and the Human Factor

Not infrequently, cases are reported of unrest or stoppages occurring in the latest type of plant, even though the most modern labour saving devices and industrial amenities have been installed. Such disputes are sources of losses which, in the end, must be borne by the consumer in the form of higher prices. Whilst incidents of this kind are to be deplored, a much greater loss arises from numerous unpublicised cases where discontent simmers for long periods and is reflected in rising labour costs, careless work and mounting prices, quite apart from reduced profits to the shareholders or proprietors of these concerns. When situations of this type are investigated, it is not uncommon to find that although full consideration has been given to technical and administrative perfection, the "human factor" has received insufficient attention at one or more levels of the organisation. Even after remedial action has been taken, a long period of time may elapse before a favourable atmosphere is achieved.

When there is no real justification for dissatisfaction or lack of harmony, the trouble may sometimes be traced to politico-industrial sources, since even a well equipped organisation can become a sterile breeding ground for those germs of discontent and imaginary grievances fostered by professional agitators or self-seekers of dubious fame. The best safeguard against trouble of this kind, leading to ever-increasing labour costs, is an alert and vigorous personnel policy, backed up by a fair but determined top management. A policy of this kind will also ensure that when justifiable points are raised by employees or their representatives, prompt action is taken before a small item of contention can become a major issue.

Not all organisations, however, have taken full steps to remove real or imaginary sources of grievance, which may be considered to be either physical or psychological in nature; the latter type usually being the most difficult to overcome.

Complaints based upon physical origins include objections to distasteful working conditions arising from dirt, noise, danger, exhausting tasks and inadequate welfare facilities. Although the Factory Acts specify minimum requirements as regards conditions of work, many companies have found that the provision of equipment and facilities in excess of legal requirements has paid handsome dividends in the form of reduced labour costs, lower labour turnover, better quality and increased output, as well as a good reputation. An active personnel policy, assisted by cooperative employees, is the best way to eliminate grievances due to working conditions. Thus, though the resultant savings may sometimes be difficult to evaluate in monetary terms, a well-run personnel and welfare department can be a wise investment, as well as a safeguard against future trouble. Joint consultation and other forms of management-operator committee can also be of help in solving this kind of problem.

Grievances of a psychological nature can effect employees at all levels, particularly those people without a spokesman to intercede on their behalf. Often these feelings are directed against other persons, rather than specific items or conditions and may be based on such origins as:

i Alleged unfairness regarding promotion, wages or conditions of work.
ii Lack of opportunity for recognition of self expression.
iii Personality clashes, jealousy, boredom.
iv Occupational unsuitability due to the work being too easy, or too difficult, or of the wrong type.

Most people are unwilling to reveal openly this kind of personal problem and except for a direct approach to management, sometimes possible only in the smaller, family-type concern, no organised procedure for impartial discussion existed until the development of reliable appraisal schemes, based upon "merit rating." It is commonly thought that such schemes are associated mainly with the payment of extra awards and bonuses based upon

the points assessed in each case. Although it is true that merit rating does provide a substantially fair method of employee appraisal and award, one of the greatest features is the periodic opportunity it presents for a frank discussion between an individual employee and a representative of management. Items of strength and weakness can be openly referred to, based on actual evidence; grievances and ambitions can be sympathetically considered and feelings of frustration or tension removed, to the benefit of all concerned as well as the work performed. Such schemes have not yet received universal adoption, but when intelligently handled, they can achieve much good for the employee and the company.

List 5 of the Appendix gives some typical items for consideration, regarding the influence of the human factor on labour costs.

Developing a Labour Cost Reduction Programme

Summarising, the fundamental items to be considered when searching for ways of reducing labour costs are:

i Primary and secondary materials.
ii Capital equipment and related overheads.
iii Direct and indirect labour.
iv Administrative functions.
v The human factor.

It is extremely unlikely that any one person in an organisation will have the necessary expert knowledge and experience in all of these fields, or the available time, to investigate every relevant factor under each heading. Nevertheless, a change under one category may influence another set of factors, so that it is essential to consider the reciprocal effect of each suggested improvement, before making a change.

In addition, someone with the requisite drive and authority must sanction further investigations into promising sources of labour cost reduction, and later give permission for any proposed changes to be made in established specifications.

Probably the best way of getting things done is to set up a small panel, which might be termed the "Economy Committee," or, say, the "Productivity Panel," headed by the managing or the works director and including one or two experienced executives. For instance, when considering the effect of changes in raw materials or plant upon labour costs, the chief chemist or chief engineer, together with the works manager might be invited to attend. Similarly, when investigating the effect of possible changes in the type of labour employed, the personnel manager and the works manager could serve on the panel. The plant work study engineer (or, if this appointment has not yet been made, the works cost accountant) could act as secretary to the panel and help to co-ordinate the investigations, as well as making valuable suggestions based on his own observations in the factory.

Such a procedure should ensure that the drive, experience and enthusiasm essential for researches of this nature will not be lacking. Indeed, it may promote savings in other directions as well as from direct and indirect labour.

Appendix

Lists 1-5 give some typical items that should be considered when investigating potential sources of labour cost reduction. These lists are by no means complete, but may serve as a useful basis for the development of a programme of work and a later course of action. It is suggested that the following questions are asked concerning each item listed and that a tabulation be made:

i Is the proposal possible?
ii Has the proposal ever been tried? If so, when? What were the results? Why?
iii What would be the probable over-all effect on labour costs?
iv Is the proposal worth following up?

After several promising items have been selected for further detailed consideration or trial, the tabulation can be extended to include the results of the investigations made and the recommended course of action. When this procedure is repeated for the appropriate materials, different types of equipment and direct and indirect labour involved, an excellent picture of the potential sources of labour savings can be obtained, together with the most effective steps to be taken in order to achieve the results indicated.

The effect of each proposed change on indirect labour costs also receive close consideration and any likely economies in the amount of supervision, control or administration should be borne in mind.

A Superabundance of Uranium?

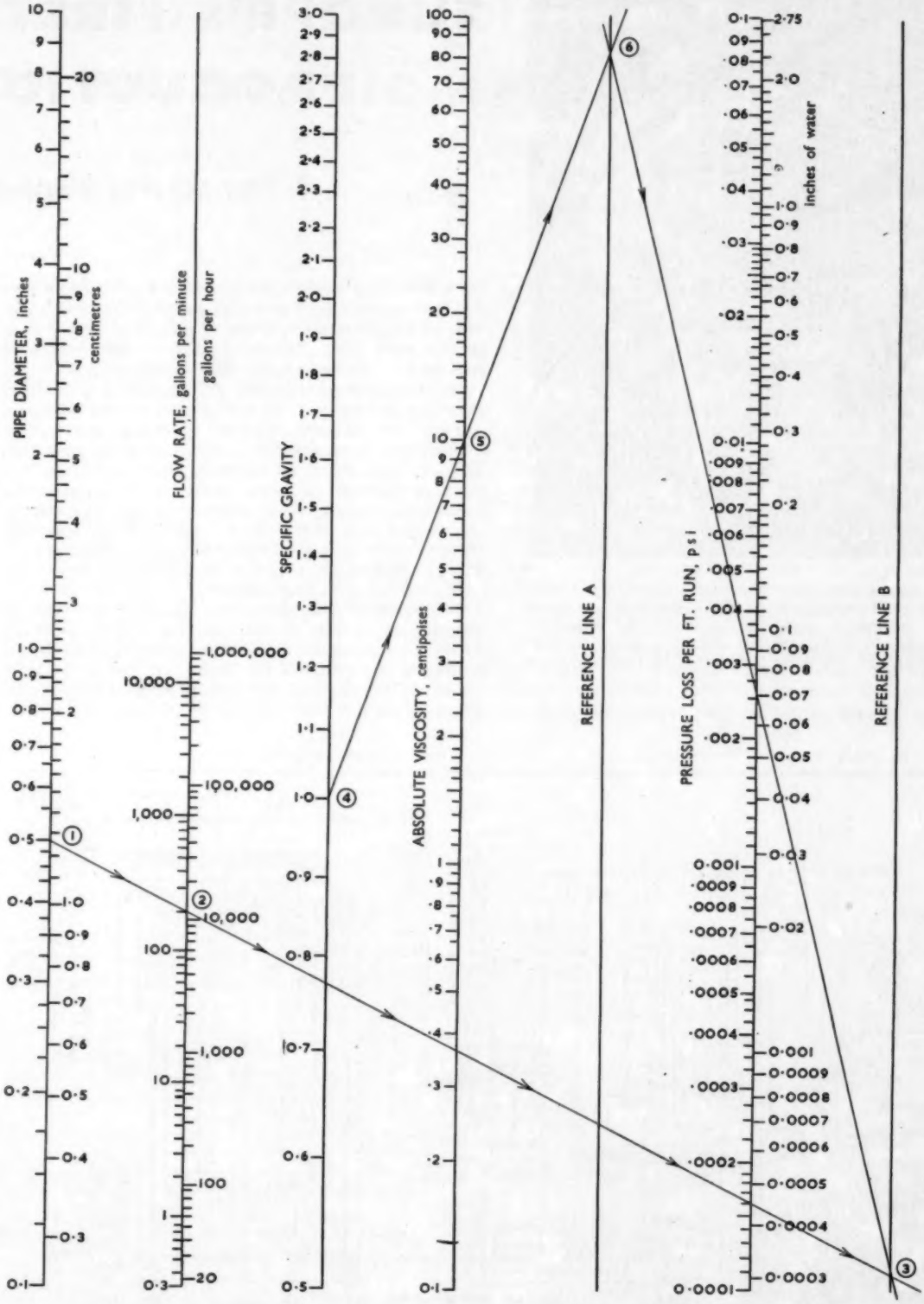
OUTPUT of uranium has expanded so fast that the producers are now beginning to think in terms of saturating the market within a few years. A most interesting forecast about future trends of uranium supplies and demands was recently made by Mr. Gerald Coke, chairman of Rio Tinto. Existing U.S. Government contracts for uranium end in 1962. Mr. Coke said that America was using between 10,000 and 15,000 tons of uranium metal a year to meet its military demand. The time is coming when the U.S.A. and Russia will have enough fission bombs on the stock to saturate all enemy targets, and Mr. Coke suggested that that would be the approximate position by 1962. After that the amount of uranium required to keep the stockpile of bomb material "topped up" would be small. Once that position had been reached he expected that uranium would then be handled through more normal commercial channels, and in anticipation of that probability Rio Tinto Management Services is now working out commercial details for the distribution of uranium.

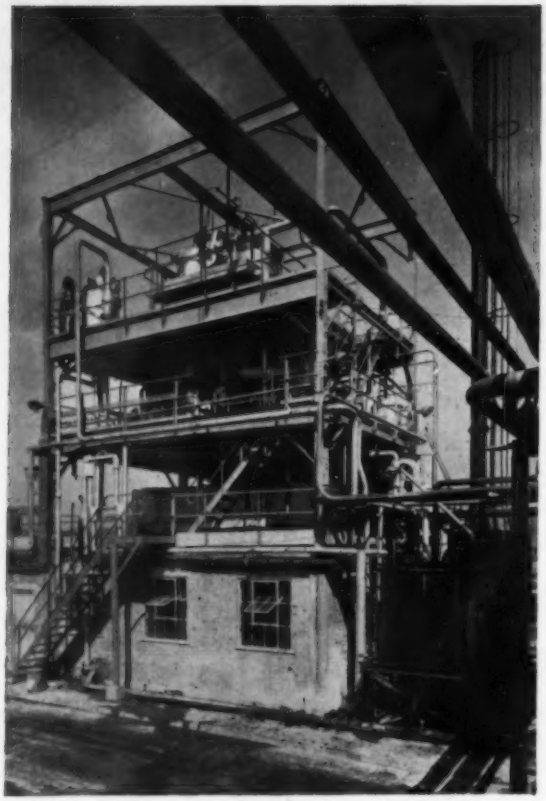
After 1962 Mr. Coke thought the demand for uranium would rise as the demand for electric power increased. On the face of it, the prospects for uranium shares looks good; to take the case of Britain, for instance, the demand for electricity is doubling every ten years. Within twenty years about a ton of uranium will be required for every megawatt of generating capacity, and on this basis Mr. Coke foresaw a world demand of about 10,000 tons a year for this purpose. But once an atomic power station is running, the amount of uranium required to replace the spent fuel will never be large, and when breeder reactors have been developed no replacement fuel will be required. Mr. Coke also referred to possibility of harnessing fusion reactions to produce power, which would have the advantage of producing no radioactive waste. The refining of uranium has been encouraged by the system of Government contracts, and output is now very large.

NOMOGRAM No. 3

The pressure loss per foot of pipe with fluid flowing in viscous or streamline state.

EXAMPLE: diameter=0.5 in.; flow rate=200 gpm; specific gravity=1; viscosity=10 cp
∴ Pressure loss (by nomogram)=0.0026 psi





The continuous catalytic unit (above) of the Littleborough plant near Rochdale. Fatty acids and ammonia reacted together to yield nitriles which are converted into amines by hydrogenation. Designed by Armour & Co. of Chicago, this plant is operated by Hess Products Ltd.

Flow diagram (below) of the Littleborough plant.

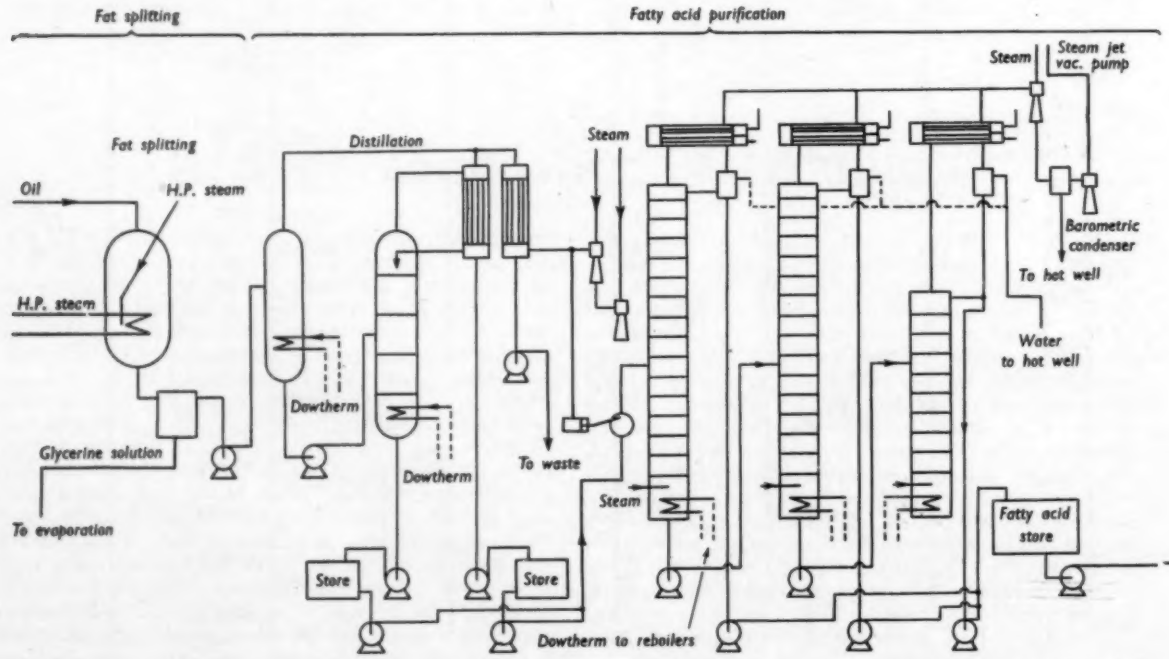
EUROPE'S FIRST PRODUCTION

A Remarkable Blend of

THE Littleborough factory of Hess Products Ltd. may be said to occupy a unique position both geographically and economically. In the first place it is very close to the most attractive inland lake at Hollingworth, a week-end haunt of anglers and yachtsmen from many parts of industrial Lancashire. It is interesting industrially because this factory is the only one in Europe producing a range of aliphatic primary, secondary and tertiary amines, and a corresponding range of quaternary salts and ethylene oxide condensation products. More and more applications are being found for these very useful substances. The long chain monoamines such as dodecylamine and octadecylamine have a number of uses stemming from their cationic nature; they are used as dispersing and flotation agents, and a further application of interest lies in the field of corrosion inhibition.

The aliphatic diamines are finding wide use as anti-stripping agents in road making and in moisture-proofing of masonry, while the quaternary salts are finding increasing application in the textile and laundry trades.

The various stages in manufacture of these products are shown in the flow diagram. The first chemical stage is the



by OUR SPECIAL CORRESPONDENT

PLANT FOR THE
OF ALIPHATIC AMINES

Batchwise and Continuous Processing

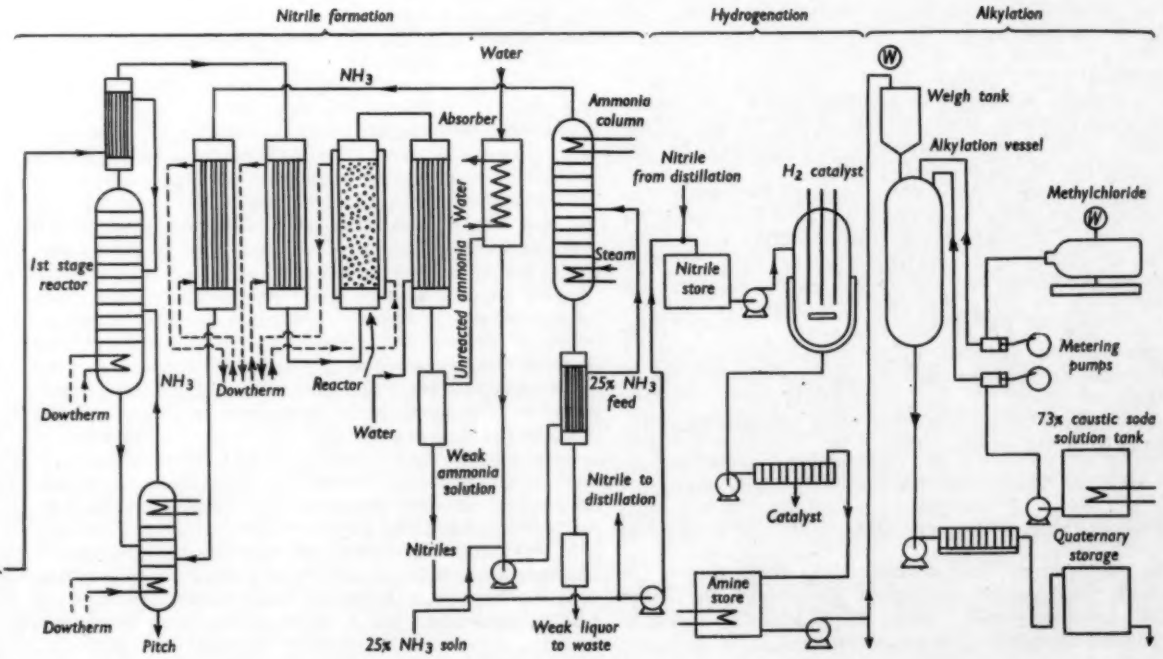
splitting of the fats and oils. During our visit we noted that the starting material in current use was whale oil. The fats and oils, which consist mainly of tri-glycerides of fatty acids, are degraded through the action of high pressure steam to corresponding fatty acids and glycerol according to the following equation:—

$$\begin{array}{l} CH_2OOCR \\ | \\ CHOOCR \\ | \\ CH_2OOCR \end{array} + 3H_2O \longrightarrow 3RCOOH + \begin{array}{l} CH_2OH \\ | \\ CHOH \\ | \\ CH_2OH \end{array}$$

The splitting is carried out at about 220°C with live steam injected at a pressure of 350 psig. The resulting acids have to be separated from the glycerol. This is effected quite simply by means of two settling tanks arranged in series. The solution of glycerol in water, which forms the lower layer, is pumped to storage prior to evaporation in a straightforward two-stage evaporator unit. Here the solution of glycerol is concentrated to approximately 90%, and is marketed at that strength.

Similary the separated acids in the top layer are pumped to storage. Subsequently they may be routed to one or both of the two distillation units which are available on the site. The choice of course depends upon the nature of the fatty acids. Before reaching this stage (i.e., immediately after the hydrolysis referred to in the last paragraph) the acids are dehydrated by flashing off the water under vacuum. In one unit a certain amount of separation is accomplished by evaporation under vacuum whereby the more volatile acids are released from the heavier ones. This evaporation is carried out at 240°C, the heating medium being Dowtherm vapour supplied from a two-drum boiler unit of conventional design. The source of vacuum in normal operation is a reciprocating piston pump, but also installed is a two-stage steam-jet ejector with inter-condenser, which is available as a stand-by and which can be used for rapid pumping down following any interruption of operation.

The materials may then be further rectified in a group of distillation columns of varying sizes. The main column of this series is provided with 25 bubble cap trays, and the general practice appears to be to introduce live steam at the lower plates of the columns to improve separation.



The re-boilers of all three columns were supplied with heat by means of liquid Dowtherm at a pressure of 10 psig corresponding to a temperature of about 280°C. The re-boilers themselves are of conventional "U" tube pattern. This Dowtherm unit, again of twin drum construction, is oil-fired and fitted with a number of controls. The heating medium is circulated by means of centrifugal pumps fitted with water-cooled glands. An interesting feature of this unit is the provision of a small still for purifying the Dowtherm at regular intervals.

The steam distillations are carried out generally under reduced pressure, the source of vacuum being provided by a two-stage ejector set with direct contact inter-condenser. Feed and delivery of products to and from the columns is effected by centrifugal pumps.

The columns are fully instrumented and include controls for re-boiler level, column feed, column pressure, live steam flow, etc. The distilled products (i.e., the purified or partially purified fatty acids) are pumped to storage; they are then either marketed or undergo further processing. In some cases, for example where the required purity cannot be obtained through a single run, the distilled material may be returned for re-distillation. The degree of purity normally achieved is about 95%. The tarry residue discarded from the re-boiler of the final column is used as fuel on the site.

Production of Amines

In the production of amines the first stage is the conversion of fatty acids to nitriles. The reaction carried out in this part of the plant may be represented in a simplified manner by the equations:

$$RCOOH + NH_3 \longrightarrow RCONH_2 + H_2O$$
$$RCONH_2 \longrightarrow RCN + H_2O$$

These reactions are carried out in two stages. In the first the heated acids are partially reacted with anhydrous ammonia on the plates of a small distillation column. The exit vapours which contain unchanged ammonia as well as amides are preheated and reacted at about 300°C in a fixed bed converter heated by Dowtherm; an activated alumina catalyst is used. The unreacted ammonia and water are separated by condensation from the nitrile which may be purified by further distillation.

An interesting feature of the nitrile plant is the ammonia supply system. In this, ammonia liquor of 25% strength is rectified in a small column and gaseous ammonia conveyed from the top of the column to the reactor. The flow of ammonia is controlled by the requirements of the reaction system.

The next stage is the hydrogenation of the nitriles. The hydrogenation plant is situated some miles away from the main site. The conditions of hydrogenation vary somewhat depending upon the type of amine required. Thus for the production of primary amines the reactions are carried out at about 200 psig at temperatures ranging from 120°C to 150°C. For secondary amines a higher temperature is required—approximately around 220°C. Hydrogen for the reaction is supplied from a small electrolytic plant.

The hydrogenation reaction involved proceeds according to the following equations:

$$RCN + 2H_2 \longrightarrow RCH_2NH_2 \qquad \textit{primary amine}$$
$$2RCN + 2\tfrac{1}{2}\,H_2 \longrightarrow \begin{matrix} RCH_2 \\ RCH_2 \end{matrix}\!\!>\!NH \qquad \textit{secondary amine}$$

The amines are returned subsequently to the Littleborough factory, for packing or further processing. The latter yields quaternary salts, usually the chloride. The reaction producing the chloride is as follows:

The pump room of the continuous nitrile unit.

$$RNH_2 + 3CH_3Cl + 2NaOH \longrightarrow RN(CH_3)_3Cl + 2NaCl + 2H_2O$$

This reaction is carried out in the presence of isopropyl alcohol; this depresses the solubility of the sodium chloride, which is therefore precipitated and can easily be separated from the quarternary salt solution by filtration. This part of the process is carried out batchwise in a closed vessel but with continuous addition of small amounts of liquid methyl chloride and 73% caustic soda solution. The latter operation is performed by a remotely controlled variable-displacement twin-cylinder metering pump. The methyl chloride is supplied from a battery of cylinders, and the 73% caustic soda is fed from a heated make-up tank through steam-jacketted pipelines to the metering pump. A filter press is used for separating the sodium chloride from the quaternary salt solution, the feed pump being a centrifugal machine. The quarternary salt solution in isopropyl alcohol is conveyed to storage tanks. (This is the marketable solution which is subsequently transported in drums or tankers.)

Of the services, steam is suplied from two economic boilers, both coal-fired and both equipped with mechanical stokers of the multi-throw type.

Steam output is about 10,0000 lb. per hour. The steam for the fat-splitting process is supplied from a small oil-fired boiler. Both Dowtherm units are oil-fired and are stated to have a capacity of around 1,000,000 Btu's per hour. Cooling water is supplied from a nearby canal to the tubular condensors, etc. However, for the barometric condensers of the steam-jet ejector sets another source of water supply is used. This consists of a closed-circuit system incorporating a cooling tower with make-up. It was noted that quantities of fatty acids accumulate in the hot well of the distillation column condensers. These are recovered periodically and sent back to the process for working-up. In lay-out, the units are spaced in a manner suggesting that a great deal of thought has been given to the problem of future expansion. The fat-splitting unit, the Dowtherm boilers, steam boilers, pump houses, instrument houses, the distillation, nitrile and quaternary salt units are all well spaced to allow extensions to the plant when these become necessary. All processing equipment is constructed of stainless steel to avoid corrosion and contamination of the products.

One commendable feature of the entire plant is the absence of any unpleasant odours despite the character of the materials being handled and manufactured. In fact, the only pronounced odour arose from the liquid Dowtherm units, which are traditionally prone to this trouble. The whole process is carried out continuously and is a really remarkable blend of batchwise and continuous processing.

AMERICAN LETTER

Industrial Research

by Dr. Lincoln T. Work

THE recent dedication of the new General Motors Technical Centre has brought again to the public view that vast enterprise known as industrial research. The part played by the president and other corporate officers in the acclaim shows how vital a part research and development plays in that business. As an example of what many industries are doing to maintain and expand their position in the race toward new and better things of life, it is representative of those whose research has matured and become integrated in the company's operations. But there are other companies where research is relatively new and has not had time to mature and become in full measure a part of the company.

A more comprehensive view of industrial research can be had in the book entitled "Industrial Research Laboratories of the U.S."* In its ten editions since 1920, it has given indication of the substantial increase in the number of laboratories in that period to a new total of 4800. In numbers alone, the growth has been around fifteen-fold, and this does not take into account the substantial growth in size of individual research units.

Such is the magnitude of this big business of invention and its application, which has grown with explosive violence over a few decades and has greatly altered our lives. Although it is not exclusive to chemistry and chemical engineering, these professions represent a substantial part of the research effort—somewhere around half its total over the years; and there are few industries in which these professions have no part. In recent years, there has been marked growth in research in the social and in the hitherto less exact physical sciences.

The National Science Foundation's premilinary report on "Science and Engineering in American Industry" presents substantial illumination on personnel and costs. Based on 15,560 companies reporting for 1953, approximately $3,700 million was spent by private industry for research and development in the natural sciences and engineering. Educational institutions, government agencies, and all other types of organisations spent an additional sum of about half that amount making an estimated total of more than $5,000 million.

Some 85% of the companies reporting had less than 500 employees; and this large group of small companies supported about 10% of all the research and development. About 70% of the total research expenditure was incurred by the 375 largest companies, each of which employed more than 5,000 people.

The chemical and glass industries contributed heavily to basic research. Food products, textile mill products, paper, ceramics, metals (both primary and fabrication), machinery, transportation and other public utilities were significantly below average in their support of research and development. Data from another source, based on percentage of sales, show drugs, industrial chemicals, and electrical machinery to be industries spending more than the proverbial 2% of turnover on research, while food, lumber, paper, and metals spend a smaller proportion.

The arrival of this new influence in industry has not been without its troubles. How to find scientists with technical and creative ability; how to run the department so as to encourage the delicate creative spirit; how to harness this creativity and direct it usefully; how to carry this same spirit through engineering development to effective operating production; how to find the right markets and the right applications for new ideas; all these problems and more caused growing pains, often of serious consequence.

The Management of Research

But the implications and management of research soon became the subject of much thought and discussion. The Industrial Research Institute, founded in 1938, now comprises a group of 145 companies interested in improving the management of research. They represent about a third of the industrial research effort in the country. Within this group, through exchange of experience and through publication of special articles, much has been contributed to the technique of research management. There is an informal organisation of universities, government, and industry which holds an annual conference on industrial research and many other conferences have been arranged recently. The problems are now well understood. Firms take great care to site their laboratories in areas which will be congenial to the professional scientist. In many cases conditions are made somewhat similar to those found in university science laboratories. Some firms are now encouraging their scientists to spend part of their time on basic research work.

As a practical matter, there is enough research history in American business to know that research development pays off. Ewell has traced the role of research in economic growth.† From 1920 until now, there has been a 3% per year growth rate in gross national product; and, with it, there has been a 10% per year growth rate in expenditure on research. Nearly $5,000 million of annual research and development expenditure today compares with $400,000 million of gross national product. During those 35 years, research and development expenditure increased from 0.2% to 1.1% of gross national product.

It takes several years for research expenditure to show major impact on gross national product. Perhaps we ought to ask just where research is leading us. How far can we afford to undertake investigations on so lavish a scale when there are limits to available capital? Are only the cream of research results going to get the support of capital? If so, are we wasting or storing the unused information? Either process is uneconomical to industry. In this dynamic age, we can only solve these problems in the tempo of the time. Quick decisions based on keen perception may keep the balance, but we must always remember that no decision is a decision.

We live better today for what chemical engineers and scientists have given from their minds. It is the real improvement in standard of living which has given a better livelihood to all of us, including the working man in the factory. As we here, and you there celebrate the anniversary of Sir William Perkin, may we recall in our common language and our common brotherhood the part that he played when industrial chemical research was but in its infancy.

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* *Industrial Research Laboratories of the United States* National Research Council, Washington, 1956.

† Ewell, R. H. *Chemical and Engineering News*, 1953, **33**, 2980.

Improved Diaphragm Pump Operation

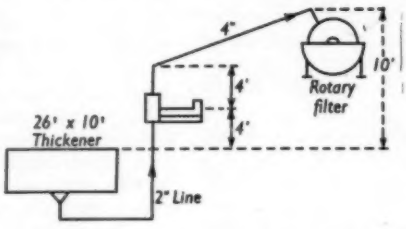
EXCESSIVE diaphragm breakage was experienced with a diaphragm pump installed in conjunction with a thickener. The pump had to transfer a lead-zinc-iron concentrate of 50% solids to a rotary disc filter. The amount of concentrate handled per day was 135 tons. The original layout of the pump, thickener and filter is shown in the accompanying illustration. After the pump makers (Denver Equipment Co.) had been consulted, the user modified his plant layout according to the advice he was given. The modifications were as follows (see illustration).

(a) To place the pump in a lower position so as to reduce the suction lift and the stress on the pump diaphragm.

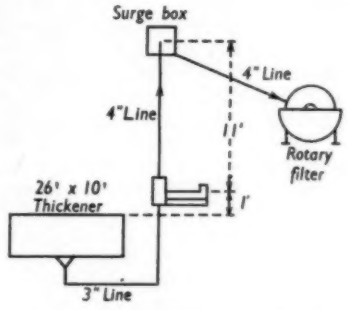
(b) To reduce friction head by pumping vertically to an open surge tank with free discharge from the delivery pipe. The pulp is discharged by gravity to the rotary disc filter.

(c) To reduce frictional losses on the suction side of the pump and thereby to reduce still further the stress on diaphragm of the pump. This was done by installing a larger diameter feed line to the pump.

The measures outlined were successful in giving a much improved diaphragm life.



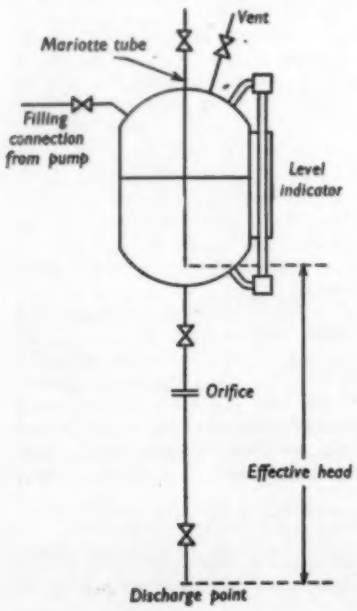
The origional layout of the pump thickner and filter.

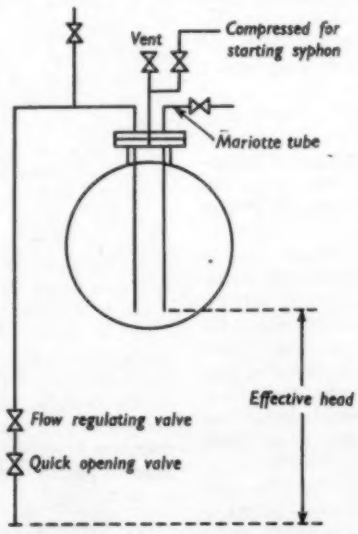


Showing the modifications carried out on the plant.

A Simple Constant Head Device

THE Mariotte tube is a simple device for obtaining a constant head of liquid. Because of its simplicity, it is worthy of wider use than it at present enjoys. All it amounts to is an open tube mounted in a closed vessel. It is desirable that the end inside the vessel reaches as near as possible to the same level as the discharge from the vessel. Once the valve discharging the vessel is opened, the effective head of the contents is the height of the bottom of tube above the discharge point in the pipeline. It is important that the vessel is closed and that air cannot enter it except through the atmospheric end of the Mariotte tube.





Examples of the use of Mariotte tubes. That on the right is preferable for handling awkward liquids.

Such a constant head tank is useful where small flows have to be controlled with accuracy and where the difference in levels for the full and empty tank is an appreciable fraction of the total head available. It is useful also where quantities are be delivered accurately in small batches. In both cases, an orifice or a needle valve may be used to regulate the flow. This must be used in conjunction with a stop valve, which should be quick-opening in applications where small batches of liquid are to be metered; in such cases the quantity is measured by time, and time lost in manipulating valves leads to inaccuracy.

The device may be used in a number of ways as shown in the accompanying illustrations. The second example (b) shows the preferable arrangement where awkward liquids are being handled, as the

problem of a damaged or stuck outlet valve does not arise. In this arrangement the syphon may be established by compressed air.

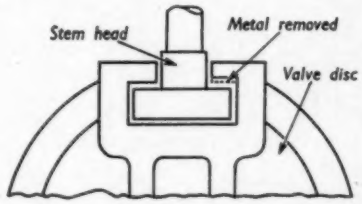
Applications are:

(1) Metering quantities from storage tanks to filling point.

(2) Controlling a small flow of liquid reactant to a low-pressure reaction system, or to a distillation column operating at reduced pressure.

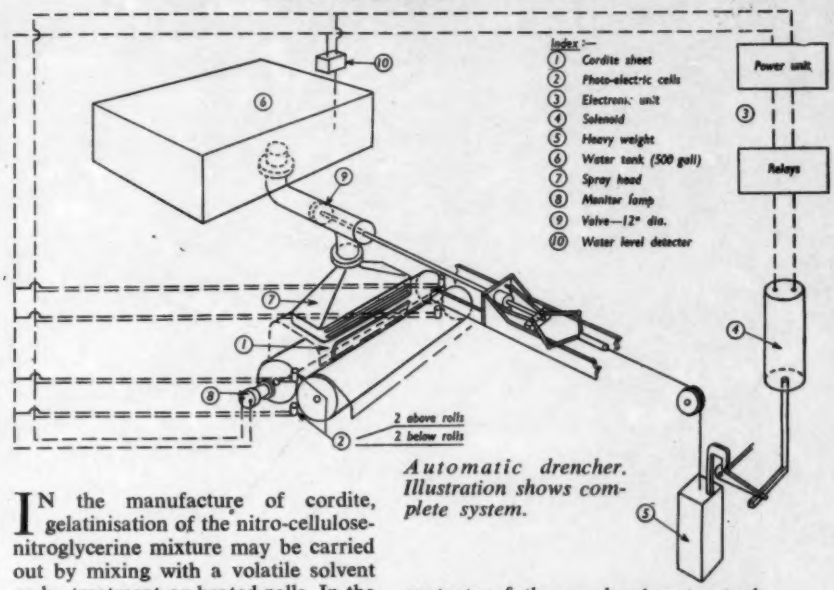
Avoiding Sticking Gate Valves

STICKING gate valves may cause a great deal of trouble in plant operation especially in cases where the offending valves are installed in remote positions and are motor-operated. The situation can arise when corrosive liquors or gases likely to deposit gummy substances are handled



by gate valves. In such cases the sticking most frequently occurs with the valve in the closed position. At one plant where this difficulty was experienced, and eventually overcome, motorised rising stem gate valves were in use. The solution to the problem was to file away about $\frac{1}{32}$ in. of metal from one side of the shoulder of the valve disc as shown in the accompanying illustration. When a valve treated in this way is opened, the upward movement of the stem head causes a slight initial twist on the valve disc, which is sufficient to disengage the disc from its seating. At the plant where this device was first used, all gate valves are now modified in this manner.

Automatic Drencher System Reduces Fire Hazard



Automatic drencher. Illustration shows complete system.

IN the manufacture of cordite, gelatinisation of the nitro-cellulose-nitroglycerine mixture may be carried out by mixing with a volatile solvent or by treatment on heated rolls. In the latter case there is a considerable hazard arising from the rolling-heat treatment process. It is possible for the sheet of cordite-nitroglycerine mixture on the rolls to ignite, and once this happens it is inevitable that it will burn with great rapidity. An automatic drencher has been devised to reduce the danger of the gelatinising operation. This system has been in operation in I.C.I.'s Nobel Division for several years, and has proved both effective and reliable.

In the event of the cordite sheet igniting (1) the initial flash is detected by one or more of the photoelectric cells (2) fixed in positions above and below the nip of the rolls. The impulse from the cells is amplified in an electronic unit (3) and energises a heavy duty solenid (4). This pulls back a catch supporting a heavy weight (5), which consequently falls. Once this weight has dropped a short distance and is in motion, the plunger of valve 9 is pulled off its seating by means of the rod and connecting linkage. The contents of the overhead water tank (6) are thus discharged through this valve and are distributed over the rolls by means of the spray head (7), which has cut in it a number of longitudinal slots. These are so designed that they not only quench the burning cordite, but also put down a curtain of water between the machine and its attendant. The drencher system is fitted with a self-monitoring device (8) and a water level detector (9), so that if a fault develops in the electronic unit, or if the tank is empty, a warning bell rings and the power is switched off the rolls. The overhead tank has a capacity of about 500 gallons of water, which is deposited on the rolls over a period of about ten seconds. The time interval between the first flash and water impinging on the surface of the rolls is about three-quarters of a second. Although the burning cordite may not always be completely extinguished, the drencher considerably reduces the severity of the fire in the initial stages and enables the operator to retire without injury.

Preventing Accidental Closing of Valves

When erection or maintenance work is carried out on a plant which is in operation, valves used by the operating staff may be inadvertently opened or shut by erection or maintenance personnel. At one plant where rising spindle valves are widely used, including valves of the outside screw and yoke type, a number of measures were tried to prevent closing of valves. In the case of valves with detachable handwheels, these were removed, and in the case of the outside screw and yoke valves hand vices were clamped to the exposed threads. However, handwheels had a tendency not to be replaced and the vices often got lost. Therefore the stem valves had a short length of $\frac{1}{4}$ in annealed copper tubing wrapped around the exposed valve stem. The presence of this tubing prevents any downward movement of the handwheel so that the valve is kept open. This method, however, cannot be used for outside screw and yoke valves. For these, a piece of stout electric cable is fixed to the yoke, threaded through the handwheel, given one or two turns around the exposed thread and tied to the rim of the handwheel. Any movement of the handwheel tending to open the valve thus tightens the cable around the screw and prevents further movement of both handwheel and the screw.

PLANT EQUIPMENT NEWS

Welding Developments

Recently shown at a Welding Exhibition in Scotland was a new "Sigma" spot welder for making spot welds in carbon or stainless steels from one side only. High quality welds can be made in lapping sheets from 0.040 to 0.125 in. thick in a few seconds while the same machine can be used for plug welding in heavier plates. The welder has a special welding nozzle and a timing device which controls the welding sequence automatically as soon as the trigger on the gun is pulled. Shielding gas is switched on first, the arc is then struck and maintained for a definite preset time interval. The flow of shielding gas is only cut off after the molten weld metal has had time to solidify. **Quasi-Arc Ltd., Bilston, Staffordshire.**

BCE 251 for further information

Spraying Catalysed Resins

With the rapid growth of the laminated plastics industry and the development of new types of lacquer finishes, a demand has arisen for a spray gun which will give an intimate mixture of resin and catalyst in predetermined proportions. The amount of catalyst must be controlled within narrow limits. For obvious reasons it is preferable that the two components should not be mixed in the gun itself. The new equipment, Ecco D4A, is specially designed to fulfil these conditions. It consists of a twin-feed spray gun fed from a catalyst metering unit. The ratio of catalyst is accurately controlled by a lever arm and plunger system which may be adjusted to give amounts of catalyst varying between 5 and 25%. The catalyst spray system may be used in conjunction with the Ecco type H3C hot-spray unit. **Atlas Copco (Great Britain) Ltd., Wembley Middlesex.**

BCE 252 for further information

Welding of Plastics

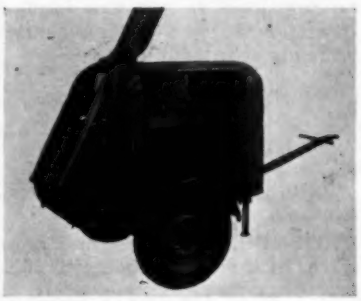
Thermoplastics, which can be repeatedly formed by heating, are easily welded by using a hot air welding gun and a welding rod of the same material. Horwich Smith & Co. Ltd., make a series of hot air guns suitable for welding such plastics as P.V.C., Perspex, Polythene, Nylon, Perlon and Polyamides. Electrically-

heated guns are made which work at low voltages for working in closed containers where there is a fire risk, in addition to guns designed to operate directly from the mains. Gas-heated welding guns can be supplied to operate on acetylene, hydrogen, and propane as well as ordinary town's gas. **Horwitch Smith & Co. Ltd., Fensnett, Staffs.**

BCE 253 for further information

Air Compressor

Agents have been appointed to market the Austrian-made "Jenbach" diesel-driven air compressor type JW 20 Kf, in this country. This model will produce 78 cu. ft per minute at, it is claimed, a cost of one shilling per thousand cu. ft. The economy is such that it is recommended these units be coupled when a bigger output is required rather than use a larger model.

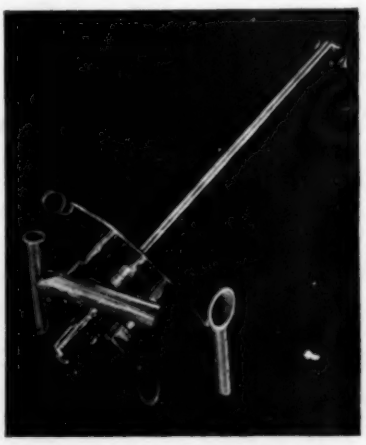


The unit is driven by a horizontal, single-cylinder four-stroke diesel driving a vertical compressor cyinder in the same block. A novel feature is the incorporation of the compressor cylinder cooling system into that for the engine. It is a water cooling system through a radiator, fan and water pump. The compressor is mounted on a two-wheel trailer. Sole Agents: **Chamberlain Industries Ltd., Staffa Road, Leyton, London, E.10.**

BCE 254 for further information

Mechanical Agitator

A new type of agitator called an "Impelator" combines centrifugal force, suction, shearing action and counter-current whirl to produce efficient mixing. It consists of a number of small conical tubes mounted round the periphery of a set of discs. One set is fitted to the bottom of a vertical rotating shaft whilst above this is another set, adjustable up or down on the same shaft according to the height of the vessel. The conical tubes are set at such an angle that controlled turbulence in an upward and down-



ward direction is created. Liquid passing through the tubes during rotation, impinges on the already moving bulk of the mass and produces rapid shearing action.

It is claimed that the device performs, in a shorter time with lower power consumption and higher efficiency, all mixing operations including the preparation of emulsions and the mixing of liquids with solids. Impelators are made in three ranges to cover laboratory needs, semi-industrial work up to 30-gal. vessels and industrial work. **Plenty & Son Ltd., Eagle Iron Works, Newbury.**

BCE 255 for further information

Oil Burner

A fully automatic oil burner with a range up to 600,000 Btu per hour has been designed for firing all types of

new, or existing, solid fuel or oil-fired boilers. Using 35 seconds heating oil it has a combustion head designed to give good working efficiencies. The burner can be controlled by room temperature, water temperature, steam pressure or time clock and is supplied complete with control box, filter and one thermostat. **C. N. Oil Burner Co. Ltd., 18 Rudolph Road, Bushey, Herts.**

BCE 256 for further information

Carbon Monoxide Detector

This is a portable battery-operated instrument which gives a continuous indication of the carbon monoxide content of the atmosphere and gives audible and visible warning of the presence of a dangerous concentration of the gas. Based on a catalytic combustion of carbon monoxide to dioxide, the instrument will operate for eight hours without servicing. Extremely portable and robust the instrument only weighs 23 lb. complete with batteries. Air is drawn in through a number of chemical purification chambers to remove gases likely to interfere with the oxidation reaction, and finally filtered before entering the reaction cell. The concentration of carbon monoxide is determined by passing the purified air over two thermistors—connected to the opposite arms of a Wheatstone bridge circuit—only one of which will be liable to a temperature increase as it is surrounded by catalyst. Obviously there is a time lag in registering the concentration as the air has to pass through a number of chambers and, finally, the thermistor chambers have to reach equilibrium, but a wave of 0.1% air would be recognised in less than a minute. A high concentration —delay is invariably proportioned to concentration — would sound the alarms in approximately 20 seconds. The instrument is fitted with two switched ranges, 0 to 0.1% and 0 to 0.5% carbon monoxide, and the alarms may be set for half-scale deflection on either range. **National Coal Board, Hobart House, Grosvenor Place, London, S.W.1.**

BCE 257 for further information

Resistant Fume Hood

The largest structures ever made in BHI Permali densified wood laminates has now completed nearly two years satisfactory service. It is an acid, soda and dye hood for a cellulose film spinning machine. Weighing over four tons, the hood measures over 63 ft long.

It has to deal with a mixture of sulphuric acid vapour and fumes from caustic soda tanks and withstands temperatures of over 100°C.

During manufacture, the procedure adopted was similar to the practice used in the design and erection of large steel structures. No reinforcing metalwork is used in the structure which in itself is completely rigid and self-supporting. The principle method of jointing is by stainless steel self-tapping screws driven in from outside and sealed off from corrosive attack. **Permali Ltd., Bristol Road, Gloucester.**

BCE 258 for further information

Portable Fire-Fighter

An entirely new type of self-contained, portable, foam fire-fighting appliance has been announced by the Pyrene Co. Ltd. The new appliance is

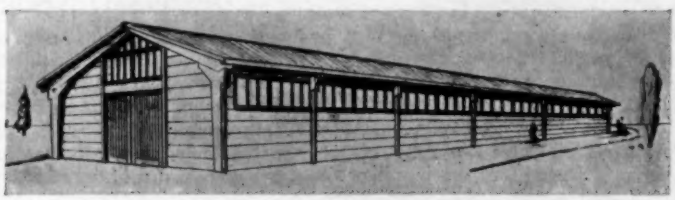
a trolley-mounted unit of 30 gal. capacity which produces more than 400 gal. of fire-smothering mechanical foam. It is particularly suitable for use where water mains do not provide sufficient pressure for other forms of mechanical foam-making equipment. Additional advantages are that it can easily be manoeuvred and operated by only one man and that re-charging can be completed within a few minutes on the spot.

A cylinder comprising the main body of the unit contains a pre-mixed solution of water and "Pyrene" foam compound. Discharge pressure is provided by a cylinder of CO_2 gas. Foam is generated at the delivery end of a 30-ft hose by a specially designed miniature "Pyrene" foam-making branchpipe. **Pyrene Company Ltd., 9 Grosvenor Gardens, London, S.W.1.**

BCE 259 for further information

Prefabricated Building

Improved designs and extended range are announced by the makers of "Cranley" prefabricated, tailor-made, reinforced concrete buildings. The main changes from the former style include a larger variety of cast window frames, special type of gable windows, overhanging verges and overhanging gutters. Patent wire-mesh reinforced roof glazing is taking the place of transparent plastic which proved unpopular with certain local authorities. A solid thin-wall concrete



panel is now offered as an alternative to the cavity panel for buildings in which insulation is unimportant. **Hewitt's of Cranleigh, Surrey.**

BCE 260 for further information

Powder Elevator

A small portable elevator to lift fine or granular powders from a low level hopper to a height of some 8 ft has

been successfully applied in handling chalk, whiting and pharmaceuticals where cleanliness is necessary. **Westhurst Ltd., Russell House, Adam Street, W.C.2.**

BCE 261 for further information

Arrester Gate

Designed to meet the requirements of a major oil company the "Hydrum" patent arrester gate and runners are used for barrel racking "on-the-roll". The barrels are held on a slight gradient with an arrester gate to hold back the remaining barrels in the rack while the one in the gate is removed. When the first barrel is clear the gate allows a further barrel to move to the front. The racks can be built in bays four high, six deep and without intervening aisles as are necessary with conventional racks. **R. H. Corbett & Co. Ltd., Hydrum Works, Burgess Hill, Sussex.**

BCE 262 for further information

Vacuum Drier

Steam-jacketed drying trays which give a high rate of heat transfer are one of the novel features incorporated into a vacuum drier now coming on to the market. Designed for the drying of delicate materials, sensitive to heat and oxidation and requiring uniform, low-temperature drying, it can be supplied in types to give batch or semi-continuous production.

The trays are automatically loaded into cells which are fully evacuated in five minutes. Low temperature steam is passed into the jacket of the tray and through the upper and lower jackets of the compartment. Drying rates of 2lb per sq. ft per hour are claimed with a steam efficiency figure of 1.1 to 1.3 lb steam per lb. moisture evaporated. Temperatures as low as 35°C can be obtained. When drying is complete the contents of the tray can be tipped into a truck by means of the simple elevator fitted.

neering Co. Ltd., Crewe, Cheshire.

BCE 263 for further information

Chemical Stripper

A new chemical stripper has been brought on to the market to strip cold-cure and low temperature stoved types of epoxy-based paints, formerly unstrippable by chemical means. The compound "Epistrip" is brushed on to the painted surface and after a quarter of an hour the paint can be scraped away easily. The stripper is not suitable for high-temperature stoved epoxy-based coatings. **Corrosion Ltd., 16 Gloucester Place, Portman Square, London, W.1.**

BCE 264 for further information

Fire Detector

The rate of temperature rise is the criterion which operates a new system of fire detection. Detector heads, suitably placed throughout a building or industrial site, feed into a single control unit which indicates by means of signal lamps, when the detector is working normally, when a fire is detected and when a fault in the circuit arises. The fire-warning signal can be relayed by means of transmitting and receiving units to Fire Brigade by P.O. telephone line.

The detectors consist of two separate tungsten wires, one of which is fully exposed to the atmosphere and the other shielded. When the temperature rises suddenly the electrical resistance of the exposed wire increases over that of the shielded wire and trips a polarised relay. Provision is made for gradual increases in ambient temperature to prevent false alarms. **Pyrene Co. Ltd., 9 Grosvenor Gardens, London, S.W.1.**

BCE 265 for further information

Degreasing Machine

A continuous ultrasonic degreasing machine has been introduced for the automatic cleaning of fine precision components such as small ball- and roller-bearings which are liable to damage by the presence of small particles of dirt not normally removed by standard degreasing machines. **Dawson Bros. Ltd., Gomersal, Near Leeds.**

BCE 266 for further information

Combined Faceshield and Respirator

Working with a shield to avoid flying particles is difficult but it is even more trying when a respirator must be worn as well to protect against dust.

The problem has been solved by the development of a combined faceshield and respirator which is worn like a space-helmet. The respirator can be fitted with three types of filters as well as a "Microfilter" to remove dust of microscopic size. **"Pulsafe" Safety Products Ltd., St. George's House, 44 Hatton Garden, London, E.C.1.**

BCE 267 for further information

Barrier Creams

Among four new barrier creams developed by Rozalex Ltd. are two of interest to the chemical industry. Cream No. 12 is designed to reflect ultra-violet rays. Originally developed to counter the effect of such irritants as tar and pitch it was found that in industries using such materials, areas of skin which were contaminated and exposed to light rays became photosensitised. A similar reaction to overexposure to X-rays or ultra-violet light is set up and ultimately causes exudating dermatitis and skin cancer. The light screen in this new cream cuts out the ultra-violet rays.

Another cream, No. 9, developed to protect against synthetic resins and glues has been shown to be resistant to water and solvents and protects against dye intermediates, plastic materials, printing inks of certain types. **Rozalex Ltd., 10 Norfolk Street, Manchester.**

BCE 268 for further information

BCE 229 for further information

CHEMICAL RESISTANT FLOOR TILING WITH A GUARANTEE—

We are able to guarantee our CORRO-PROOF Chemical Resistant Floor Tiling because it is—

- Laid by Craftsmen specialising solely in Corrosion Resistant Tiling.
- Laid in CORRO-PROOF Chemical Resistant Cements which are recognised as the QUALITY Acid-Proof materials.
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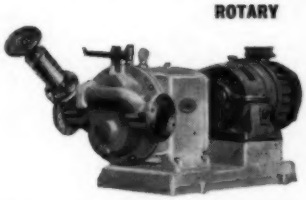
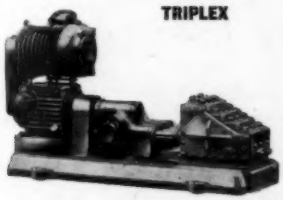
ROTARY



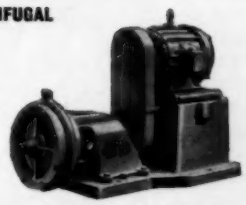
For pumping heavy viscous liquids, and sensitive fluids when violent agitation would be harmful the Howard 'M' type Easy Cleaning Rotary Pump is ideal. Made in seven sizes for capacities from 100—20,000 GPH manufactured in stainless steel and other corrosion resistant alloys, jacketed pump casing if required.

TRIPLEX



For those services requiring an "even flow" against high pressures the Howard Triplex Pump is available in three sizes, 5, 10, 20 HP with wide choice of liquid ends giving outputs up to 6,000 GPH and pressures of 12,000 p.s.i. jacketed liquid ends supplied, also double check valves if required.

CENTRIFUGAL



Available in two designs—the normal type with closed impellors and flanged connections for chemical industry, and the easy-clean type with open impellor and all internal parts smooth machined, specially for the Food and Dairy Industries. Both types have circular casings permitting outputs from 5—300 GPM for heads up to 140 p.s.i. can be supplied if required with mechanical gland seals also jacketed casings when called for.

In food and chemical production, and in many other industries these four different types of Howard Pumps have proved their efficiency in many fields. Although each one has a specific range of functions, all are designed to withstand constant hard use and are remarkably simple to clean and maintain.

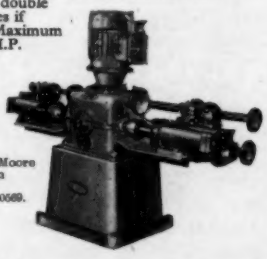
FOR THE MOST HIGHLY CORROSIVE CHEMICALS All Howard Pneumatic Pumps can be supplied in stainless steel, or in any anti-corrosive alloy which is machinable, also available in Steel, Bronze, Aluminium, etc.

FOR REMOTE CONTROL BY INSTRUMENTS Proportiometer and Triplex Pumps can be supplied ready for instrument control so as to permit a substantial saving in manpower.

Write for fully descriptive literature on the complete range of pumps available, to

PROPORTIOMETER

A variable capacity plunger pump for accurate metering service, made in four sizes for capacities ranging from a few c.c. per hour up to 2,000 GPH, can be supplied for pressures up to 2,000 p.s.i. liquid ends steam jacketed and fitted with double check valves if required. Maximum rating 20 H.P.



Made under Moore and Charlson Patent Nos. 476953 and 500569.

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BCE 230 for further information

Book Reviews

Chemical Engineering. Vol. II

by J. M. Coulson and J. F. Richardson
Pergamon Press, London, 1955. 588 pp., 60s.

THE expansion of chemical engineering teaching in this country has been somewhat handicapped by the lack of good textbooks at a reasonable price. The standard Americans texts are expensive, and unless the student is prepared to purchase a number of the specialised monographs he must supplement his lectures by much library work. A real effort has been made in recent years to overcome this difficulty by the production of English texts, and more particularly by publication of a number of excellent monographs. A comprehensive textbook, suitable for use throughout a three-year honours course, bringing together fundamental principles with details of unit operations and plant and equipment, was however still required. This requirement Prof. Coulson and Dr. Richardson have attempted to meet in the two volumes of *Chemical Engineering*, of which Volume II, dealing with unit operations, has now been published.

The book consists of five sections, each of three or four chapters, dealing respectively with the following subjects: flow of fluids past particles (flow of fluids through granular beds and packed columns, filtration, the centrifuge); systems involving relative motion between a fluid and particles (motion of a particle in a fluid, sedimentation, fluidisation and conveying, gas cleaning); applications of mass transfer in chemical engineering (leaching, distillation, absorption of gases, liquid-liquid extraction); evaporation, crystallisation and drying; size reduction, classification of solid particles and mixing. Each chapter contains an account of the basic principles of the unit operation, and develops from these principles the design methods required. An account of the various pieces of equipment used in industry with some note of the relative advantages of the different types illustrated is then given. The chapters are well illustrated by actual photographs of equipment as well as by clear line drawings and graphs.

As in Volume I, mathematical treatment has been used extensively, and wherever possible exact mathematical derivation of equations has been given. This is of considerable value to the student in that it places the emphasis on fundamental principles rather than on empirical correlations. Unfortunately practical data does not always agree with theoretical prediction and in certain instances these differences have been left unexplained. Throughout the work reference is made to the more important recent publications. Whilst this is of great value to research workers, it gives the text a mixed character, in part that of a standard reference book and in part that of a review. It will however stimulate the student to much wider reading in his subject and provide him with the necessary references to permit this.

The production of the work is good but does not reach the standard established in Volume I. There is a suggestion that too much has been attempted in this second volume, and it might have been better divided into two books, although this would have increased the cost. There are one or two minor errors which should be corrected in subsequent reprintings. Despite these criticisms the book does fulfil the authors' purpose and provides a textbook for university students which will be a standard reference text for many years. The book will also be welcomed by chemical engineers in industry and by research workers who will find much in this book to stimulate and guide their work.

F. MORTON.

Reactor Handbook: Volume I Physics; Volume II Engineering; Volume III Materials.

McGraw-Hill, New York and London, 1955. Vol. 1, 804 pp., 90s.; Vol. 2, 1088 pp., 112s. 6d.; Vol. 3, 614 pp., 79s.

THESE books are three out of the six volumes of information collected by the United States Atomic Energy Commission to give delegates to the Geneva Conference on the Peaceful Uses of Atomic Energy background information on the technology of nuclear energy and its applications.

Volume I is subdivided into the two main branches of physics involved in reactor technology: reactor physics and radiation shielding. The second volume provides an over-all view of the engineering of basic reactor systems. The book is divided into eight sections covering fixed fuel reactors using aqueous, liquid metal and gas coolants, fluid-fuel reactors using slurries or solutions with aqueous, liquid metal and fused salt coolants, a special section on reactor control and a summary of various designs for experimental and research reactors. The final volume surveys the many interesting and novel materials used in reactor construction and presents detailed tables of their physical, chemical and mechanical properties.

Chemical Processing and Equipment

McGraw-Hill, New York and London, 1955. 316 pp., 45s.

THIS is one of the six volumes on the technology of nuclear energy prepared by the United States Atomic Energy Commission. It is divided into two parts: the first deals with the chemical processing of irradiated fuel elements and the second with laboratory techniques for handling highly radioactive substances. The information on chemical processing describes features of the American reclamation plant and includes flow sheets and illustrations of some parts of the equipment. The second part is a descriptive list of apparatus which has been developed in the United States for handling and manipulating highly radioactive materials in laboratory amounts.

Proceedings of the International Conference on the Peaceful Uses of Atomic Energy. Volume 3: Power Reactors

United Nations, New York, 1956. 389 pp., Price 54s.

THIS is the first volume to appear of the sixteen which constitute the official proceedings of the Geneva Conference. The book contains detailed information about all the power reactors in existence or being constructed, including the Russian power station and the Dounreay fast reactor.

Quite the most interesting part of the book to the chemical engineer is that which describes designs for homogeneous reactors. In the homogeneous reactor, the fuel moderator and coolant are circulated through the reactor itself and through the heat exchangers. A feature of these designs is that the circulating fuel may be treated continuously for the removal of fission products which poison the fission reaction. The homogeneous reactor is thus essentially a chemical plant involving all the usual design difficulties and in addition the exceptional problems which arise from the intense radioactivity generated in the core.

A group of papers is also devoted to the comparison, from economic and other aspects, of various possible fuel cycles. The general conclusion is that the cycle using U233 produced by the action of neutrons on thorium is likely to have the highest conversion factor and should be of great importance in the future.

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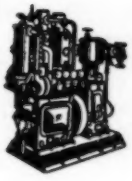

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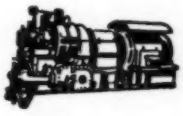

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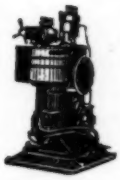

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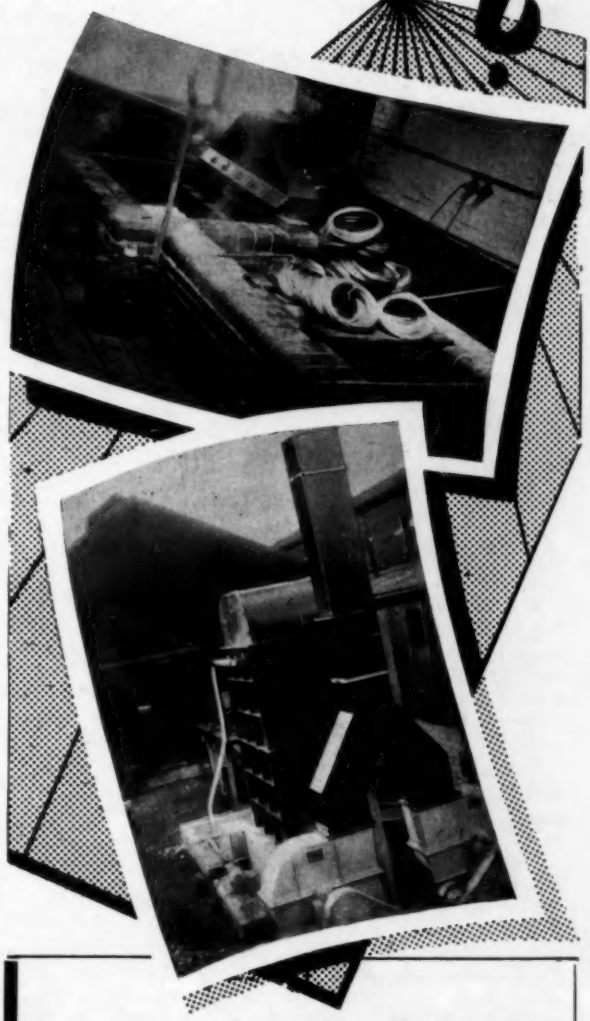

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The Month's News in Brief

News Briefs

To meet the steadily increasing demand for ethylene and propylene derivatives, Petrochemicals Ltd., a member of the Royal Dutch/Shell Group of companies, has started work on an extension to its Partington plant. These new facilities will include a plant for the production of some 25,000 tons a year of ethylene oxide. To keep in step with the increased capacity, other site facilities such as steam and power generation, cooling water, workshop, stores, etc., are also being enlarged. The facilities are expected to be in full operation by mid-1958.

Henry Wiggin announce that they have purchased the specialised high nickel alloy fabricating plant at Hereford, which they designed and erected for the Ministry of Supply and have been operating since 1954. The company is a wholly-owned subsidiary of The Mond Nickel Co. Ltd., an affiliate of The International Nickel Co. of Canada.

A £1 million elastomers laboratory has been opened by E. I. du Pont de Nemours & Co., in America. The installation is designed to provide technical service on "Neoprene" and "Hypalon" synthetic rubber, and will prove an important addition to the facilities already offered by Durham Raw Materials Ltd., the U.K. distributors of these Du Pont products.

Comdr. Colin Buist, chairman of Coalite & Chemical Products, pointed out in his statement for the year to 31st March, 1956, that as the cost of plant continues to rise the final bill for the company's current investment programme would amount to £1 million at least.

The Rheostatic Co. Ltd., Slough Bucks, England, announce that owing to recent wage increases and the rising cost of raw materials, they are obliged to effect a general price increase on their products. The prices will become effective from 1st September, 1956.

An explosion at the factory of Explosives and Chemical Products Ltd. killed one woman and injured two others. The explosion occurred in one of the many small sheds in which the bagging of nitro-cotton is carried out.

Monsanto Chemicals Ltd. were ordered to pay £14,000 damages and £5500 costs for the pollution of the River Dee in N. Wales. A perpetual injunction was granted by Mr. Justice Harriman, the operation of which is suspended until June 30, 1958, to enable the company to find a solution to this pollution problem.

The directorship of the Association of British Chemical Manufacturers has now been advertised at a salary of around £4000.

British Industrial Solvents announce that the U.K. prices of "BISOL" acetoacetanilide and acetoacet-o-chloranilide have been reduced by £50 and £75 per ton respectively, with effect from 1st June, 1956.

Matthew Hall have been awarded a contract to the value of £2 million in connection with extensions to I.C.I.'s fertiliser plant at Billingham.

Shell have signed a ten-year agreement with the North Thames Gas Board for the supply of refinery gas.

L. B. Holliday & Co. Ltd., Huddersfield have been supplied with a steel autoclave cover casting capable of withstanding a pressure of 1200 lb. per sq. in., by the Edgar Allen Steel Foundry. The casting measures 4ft 10 in. dia. x 7½ in. thick and weighs 21 cwt. 3 qrs.

Bowaters new U.S. pulp mill in South Carolina will cost some £36 million.

Spencer - Bonecourt - Clarkson Ltd. have moved to Lynton House, 7-12 Tavistock Street, London, W.C.1. Tel. EUSton 4321.

K.D.G. Instruments Ltd., have moved to Manor Royal, Crawley, Sussex. Tel. Crawley 25151.

Bowser oil lubricating and filtration systems are now being made and marketed by Liquid Systems Ltd., Union Road, Croydon.

Coming Events

A European conference on inter-firm comparison, sponsored by the British Institute of Management and the European Productivity Agency, will be held in Vienna from 17th to 20th September, 1956.

The 6th International Technical Exhibition will be held at Turin from 29th September to 6th October, 1956.

The 26th Exposition of Chemical Industries is to be held at the new Coliseum in New York, 2nd to 6th December, 1957.

The 31st Brussels International Fair will open on 27th April, and close on 12th May, 1957.

The Canadian National Exhibition is being held at Toronto from 24th August to 8th September, the British Government will have a stand on which there will be a display illustrating the United Kingdom's scientific and technical achievements since the war.

The 41st Physical Society Exhibition in 1957 will be held in both the Old and New Halls of the Royal Horticultural Society, Westminster, London, S.W.1, from 25th to 28th March.

Atomics

The honour of selling the first British-made nuclear reactor overseas has gone to the Associated Electrical Industries and John Thompson team. The reactor is an experimental "swimming bath" reactor and is going to Germany.

Ruberoid are to supply 29,000 sq. yd of insulated steel deck roofing to the U.K.A.E.A. for buildings housing laboratories and processing plant.

Belgium's first nuclear reactor is now in operation at new laboratories near Antwerp. The reactor will be used to study various civil applications of nuclear energy.

A grant of $250,000 has been made by the Rockfeller Foundation to the National Academy of Sciences for a two-year study of the dangers to present and future generations from atomic radiation.

Headquarters of the International Atomic Energy Agency to be set up by the United Nations will almost certainly be located in Vienna, now that both Russia and the United States have given support to this choice of site.

America is to supply research reactors to West Germany. The reactors (two to three) will be supplied within 12 months after the contract has been signed although no final date for conclusive negotiations has yet been fixed.

McGraw-Hill

COMING BOOKS

General Electric Company Inc.
edited by Hugh N. Powell
Properties of Combustion Gases
volume 1
Thermodynamic Properties
volume 2
Chemical Composition of Equilibrium Mixtures
the set approx **£28**

These volumes, composed of tables with a brief introductory text, provide an accurate account of the thermodynamic properties and behaviour of the working fluid of the air-breathing combustion engine. They will be valuable to those working on combustion research, the development of gas turbines and turbojet engines, and aircraft ana missile propulsion; and to chemical companies engaged in the high-speed high-temperature synthesis of materials from combustion-type reactors.

E. W. Comings
High Pressure Technology
86s 6d

A text and reference book for advanced students and for engineers and scientists doing industrial or laboratory work at high pressure. It emphasises the influence of high pressure on chemical and physical systems, and on the design of equipment for handling those systems.

W. L. McCabe and J. C. Smith
Unit Operations of Chemical Engineering
approx **75s**

A unified treatment of the unit operations of chemical engineering from a practical and theoretical point of view, designed for undergraduate students. Each unit operation is treated separately; fluid mechanics, flow of heat and mass transfer are included.

J. M. Smith
Chemical Engineering Kinetics
60s

This book combines applied kinetics with a discussion of the engineering problems encountered in designing chemical reaction equipment. It has been written for the third and fourth year undergraduate, the graduate student and the practising chemical engineer.

U.S. Atomic Energy Commission
edited by Theodore Rockwell
Reactor Shielding Design Manual
45s

Describes practical methods for designing, constructing and testing shields for reactor plants. They are based on experience, and take into account the problems of plant layout, structure and maintenance. The material has been tested in naval and water reactors.

U.S. Atomic Energy Commission
Chemical Processing and Equipment*
45s

The first section of this book describes the chemical processing of irradiated fuel elements to reclaim highly enriched uranium. The second section is a catalogue of equipment and tools used for the safe handling of irradiated materials in laboratory work.

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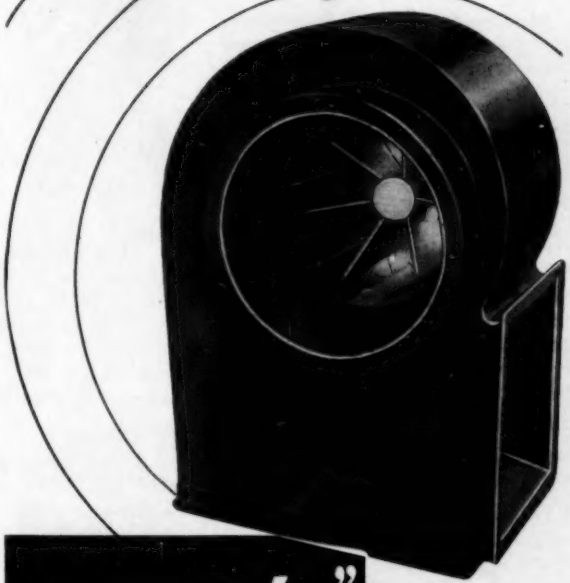
The Fan for the Chemical Industry



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SWANSEA: 256 Oxford Street. *Phone: Swansea 50149*
Associated Company, Johannesburg, S.A.

The Costa Rican Institute of Electricity (I.C.E.) has recommended the creation of a National Commission for nuclear matters to be composed of representatives of the University of Costa Rica, I.C.E., and the Office of the Presidency. The suggestion is that the Commission should collect material on the uses of atomic energy, promote scholarships for students to study nuclear physics, and investigate any natural radioactive resources in the country which might appear suitable for commercial development. It is emphasised that active interest in nuclear matters must necessarily be restricted in view of Costa Rica's limited resources and her primary interest in developing her large hydroelectrical potential.

People

Mr. Noel Ream of the National Physical Laboratory has been appointed editor of the *Transactions* of the Society of Instrument Technology in succession to **Dr. Harold Moore,** C.B.E. Other changes announced at the Society's annual general meeting were the elections to council. These are as follows: User Group: **G. C. Eltenton** (Shell Refining & Marketing Co. Ltd.) and **R. Riley** (Costain-John Brown Ltd.) vice **Mr. P. F. Cook** and **Dr. R. Jackson.** Manufacturers: **Mr. R. S. Medlock** (Director, George Kent Ltd.) vice **Mr. H. R. Walton.** Education and Research: **Professor A. Porter** (Imperial College of Science) vice **Dr. G. D. S. MacLellan.**

The National Council for Technological Awards have appointed **Mr. F. R. Hornby,** M.B.E., M.A. as their secretary. Mr. Hornby will take up his duties on 1st September. In the meantime all communications should be addressed to the Acting Secretary to the Council at the Ministry of Education, Curzon Street, London, W.1.

Mr. H. A. Collinson, F.R.I.C., the technical director of Leicester, Lovell & Co. Ltd. since 1946, has been appointed assistant managing director, and **Mr. P. G. Pentz,** B.Sc., and **Mr. B. E. G. Massey** have been elected to the board of directors.

Megator Pumps & Compressors Ltd. have appointed **Mr. James Longmuir,** Jnr., as an additional Scottish technical representative. **Mr. Longmuir,** Snr., already represents the company in the same area.

Dr. E. W. R. Steacie, President of the National Research Council of Canada, has been awarded the honorary degree of Doctor of Science by the University of Ottawa.

Scottish Agricultural Industries Ltd. announce that **Sir William Gavin,** C.B.E., has resigned the chairmanship of the company and from the board, on reaching the age of 70. A director for twenty-five years and chairman since 1951, he has seen the turnover of the company increase from some £3m to £23m. The board has appointed as his successor **Mr. W. Donald Scott,** a director of Imperial Chemical Industries Ltd., who has had intimate experience of the national and international fertiliser industry. Mr. Scott has been a director of Scottish Agricultural Industries Ltd. since 1952.

F. R. Livock

W. Donald Scott

The Council of the British Institute of Management announces the appointment of **Mr. F. R. Livock,** T.D., B.Sc.(Eng.), M.I.E.E., M.I.Mech.E., as a director. Mr. Livock succeeds the Hon. L. O. Russell who resigned as director last December with effect from 30th June, 1956.

The Baird & Tatlock group of companies announces that **Mr. J. B. Longman** has been appointed technical sales representative for South London and South-East England in succession to **Mr. P. H. D. Andrews** who is returning to South Africa.

Sir Francis Simon, who has been Professor of Thermodynamics at Oxford University since 1949, has been appointed Dr. Lee's Professor of Experimental Philosophy at Oxford and will take up the appointment on 1st October. He succeeds **Lord Cherwell.**

Mr. M. Shaw, B.Sc., A.R.I.C., A.M.I.Chem.E., has resigned from Shell Chemical Co. Ltd. and its subsidiary Petrochemicals Ltd., and has joined Petrocarbon Developments Ltd. as the assistant technical manager of the design and development offices at Manchester.

Mr. J. S. Crawhill has been appointed to the board of the Cementation Co. He remains managing director of Cementation Co. (Africa) (Proprietary).

Mr. Marshall E. Young, a vice-president of Monsanto Chemical Co., has been elected a director of Monsanto Chemicals Ltd.

Prof. Frank Morton is leaving Birmingham University to become the first occupant of the new chair of chemical engineering at the Manchester College of Technology. It was at this college that he graduated in 1930 in Applied Chemistry, subsequently taking an M.Sc. degree in 1931, Ph.D. degree in 1935 and D.Sc. degree in 1952. He went to Birmingham University in January, 1949, as Reader in Chemical Engineering and was appointed Professor in Chemical Engineering in the following October. His principal researches have been concerned with distillation and methods of separating hydrocarbons in the middle boiling range. Prof. Morton is also interested in the separation of tar acids and tar bases by solvent extraction, and in the combustion of hydrocarbons, particularly in diesel engines.

Prof. M. Stacey, F.R.S., has been appointed as Mason Professor of Chemistry and Head of the Department of Chemistry of Birmingham University with effect from 1st October next. He succeeds **Prof. H. W. Melville,** F.R.S.

New Publications

Leaflet No. 289 is produced by Kestner and gives wide details of the company's Automatic Gas Washers. Kestner Evaporator Engineering Co. Ltd., 5 Grosvenor Gardens, London, W.1.

The Manesty "DryCota" is a 6-page brochure giving details of Manesty Machines Ltd., combined tablet making and compression coating machine. Manesty Machines Ltd., Speke, Liverpool 19.

Freight Handling, a BPC productivity review is of interest to all those concerned with the handling of freight. British Productivity Council, 21 Tothill Street, London, S.W.1. Price 5s.

The 1956 edition of Who's Who in the Gas Industry is now available. A buyers guide is included. Arrow Press Ltd., 1 Stamford Street, London, S.E.1.

Lights Organic Chemicals, 1956. The latest list is now available on application to L. Light & Co. Ltd., Payle Trade Estate, Colnebrook, Bucks.